THE ACOUSTIC IMPEDANCE MEASURED ON NORMAL AND PATHOLOGICAL EARS

ORIENTATING STUDIES ON THE APPLICABILITY OF IMPEDANCE MEASUREMENT IN OTOLOGICAL DIAGNOSIS

BY

OTTO METZ

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COPENHAGEN 1946

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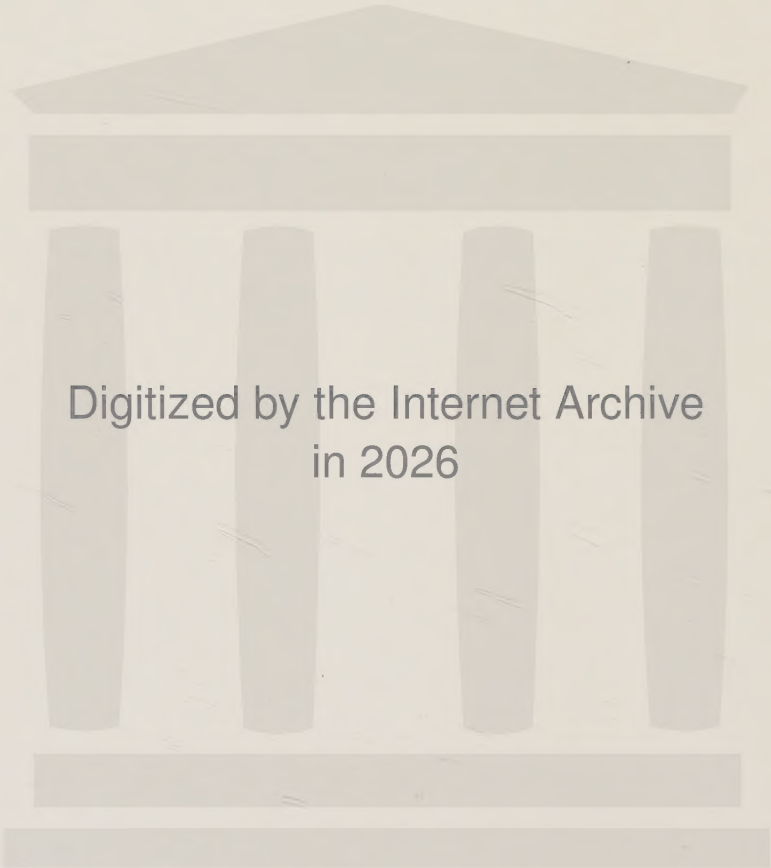
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Denne Afhandling er af det lægevidenskabelige Fakultet antaget til offentligt at forsvares for den medicinske Doktorgrad.

København, den 4. April 1946.

H. C. A. Lassen.
h. a. dec.

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PREFACE

The present studies were commenced after, through the works of *v. Békésy*, I had realized the eventual significance of the impedance measurement in the otological clinic, and after I had found a suitable apparatus for this purpose in the work of *Waetzmann*.

My wish to tackle the problems involved met at once with encouraging interest on the part of Professor *H. M. Hansen*, Ph. D., Director of the University Institute of Biophysics, Copenhagen, who had the measuring bridge made for me and afforded me some excellent working conditions in the institute.

Amanuensis *V. Thorsen*, Ph. D., has always been ready and willing to advise and help me concerning the physical part of the work. Without this assistance it would have been impossible for me to carry through this work. Besides, many instructive discussions have made me see more clearly some aspects of physical acoustics essential to the understanding of the theoretical foundation for the measuring bridge and its employment.

The work was started during my appointment as assistant physician to the Ear, Nose and Throat Clinic of the Rigshospital, 1939-1940. In the greater part of this period, however, I was occupied mostly with entirely physical investigations. Professor *A. Thornval*, M. D., Chief Physcian, has taken a great interest in my work, and he furnished me some excellent working conditions also after I had left this department, besides permitttng me to examine the patients in the clinic.

During my following service in the Øresund Hospital, Dr. *N. Rh. Blegvad,* Chief Physician, placed adequate quarters at my disposal, with permission to examine the patients.

Mr. *V. Thygesen,* Master Mechanic, has made the measuring bridge for me and assisted me technically in various model experiments.

Naturally the world war II brought some obstacles to the progress of my work too, delaying its conclusion greatly.

During my enforced stay in Sweden from November 1943 to the capitulation I was received most kindly and hospitably by Professor *Gösta Dohlman,* M. D., who was generous enough at once to offer me an opportunity to continue my studies. Several of the anatomical experiments were carried out in the Ear, Nose and Throat Clinic of the University of Lund.

I wish to acknowledge my indebtedness to all the persons mentioned here. Finally, I wish to give my best thanks to the nurses in the Ear Clinic of the Rigshospital and in the Ear Clinic of the Lund University for all their kind assistance.

The translation of this book from Danish is done by Lector *Lionel Hewitt.*

Copenhagen, September 1946.

OTTO METZ

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ABBREVIATIONS

Imp. = impedance = $w + jq$.

The Imp. of "an ear" = the acoustic impedance measured in the auditory canal in a plane fixed for each individual ear.

Abs. = a = the absorption coefficient.

Phase = ϑ = the phase difference.

u = $\dfrac{\bar{w}}{\bar{w}^2 + \bar{q}^2}$ = »der Übertragungsfaktor« (transmission factor).

A small line above the magnitudes $\bar{w}$ and $\bar{q}$ means that they are calculated with the wave resistance in air as unit.

A small line above X ($\bar{X}$) is used to indicate the mean value of a magnitude placed as index of X (for example $\bar{X}_a$ = the mean value of Abs.).

In all the diagrams ϑ and $\bar{q}$ are to be read with minus sign (—).

INTRODUCTION

One of the two problems of acoustic function diagnosis — the determination of the degree of the reduction of hearing — has in the main been solved. The other problem — the determination of the cause of the reduction — is much more difficult. Its solution is for the present limited to an attempt at diagnosing the location of the affection, but this local diagnosis even in its most simplified form: differential diagnosis between sound-conduction and perception deafness — still presents great difficulties.

Simultaneously with the fundamental investigations in the sound-conducting apparatus of the ear, which were performed during the second half of the past century, it was endeavoured by various means to find a clinically applicable method for testing the vibrating efficiency of the sound-conducting apparatus of the living ear.

These endeavours being unsuccessful, the investigations receded into the background in favour of the function diagnosis, the foundation of which was laid during the same period, particularly by *Bezold*'s works. Later it has steadily developed further and, after the introduction of the audiometer, has progressed still more. The *subjective function diagnosis,* as it may be called, is now the chief method for the differential diagnosis between conduction and perception affections. It is an indirect method. The patient is tested as to what he is able to hear or, more correctly, what he cannot hear, and the diagnosis is made on the ground of pathologico-anatomical, experimental and clinical experiences. The vast literature from recent years, however, tends to show the disagreement still prevailing with regard to the estimation of the different hearing tests.

That attention has been focussed on the other possible way of diagnosing a conduction affection, namely, by direct *objective demonstration* of it, is evident from the experiments which have also been made recently, but which have not either led to any practically applicable result.

Particularly during the last twenty years, however, an enormous development has taken place within physical acoustics and, subsequently, within physiological acoustics too. This development has taken place partially on the ground of comparison between mechanical-acoustic systems and analogous electric systems, which is easier to survey and make the subject of calculations. This electro-mechanical mode of presentation according to *v. Békésy* probably is the chief reason why the progress of acoustics has taken place partially unnoticed by otologists.

In physical laboratories it has been possible already several years ago (1928—1930) to determine the vibrating efficiency (the so-called acoustic impedance) of the tympanic membrane fairly accurately and to plot characteristic curves for different persons, whence (cit. after *v. Békésy* 1939) it must be assumed that characteristic and measurable changes of the vibrating efficiency may also be demonstrated in case of morbid changes of the middle ear. (As the ear receives the sound energy through the drum, it may — according to *Waetzmann* — be permissible to use the term the impedance of the tympanic membrane as an abbreviation instead of the impedance of the tympanic membrane + the sound-conducting apparatus.

The first means with a possibility of application in clinical otology was supplied by *Schuster* in 1934 by his acoustic measuring bridge which had been constructed for another purpose. In 1938 *Waetzmann* performed the first measurements on ears with dimensions of the original measuring bridge adapted to this purpose.

Physicists have previously carried out impedance measurings only on some normal persons and on very few pathological ears, and there is merely a question of indifferently selected affected ears. Nor is any normal material on record in the

literature. The clinically most interesting examinations of ears with conduction anomalies and normal drums (f. ex. otosclerosis) were not carried out in any case. From otological quarters no reports of impedance measurements have been published in the available literature.

It therefore seems natural now to apply this measuring method in the otological clinic in order to see what it affords particularly in the diagnosis of conduction affections and the differential diagnosis between sound-conduction and perception affections. That is the scope of the present investigations. My endeavours to solve the set task naturally have led me to scattered kindred subjects within the physiology and pathology of the ear. All the examinations require further study, but I think that the results obtained have so reliably disclosed the great possibilities of the method that it is warrantable to publish them now.

A difficult task is the description of the physicism required for the comprehension which otologists cannot be expected to be acquainted with. I have endeavoured in a very brief summary to define the most important fundamental notions from the acoustics, even though I am quite aware, that physicists will regard it as very imperfect, and at the risk of being of but little help to otologists.

In order that the first chapters shall not scare readers too much it must be mentioned that a thorough understanding of the physicism is not necessary for the estimation of the clinical results. Without paying much regard to the complex impedance, one may content with — what the writer partially has done — studying the two directly measured magnitudes, i. e. absorption and phase, and see how they behave in different ear diseases or by what changes they respond to experimental changes of the vibration efficiency of the tympanic membrane. For the physical estimation, however, it is absolutely necessary to pay regard to the very impedance and its components.

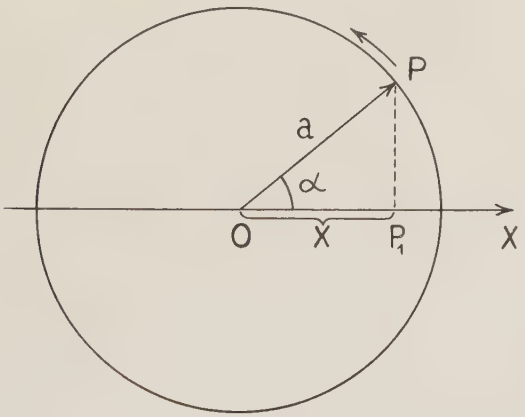
The graduation of the measuring bridge is described in detail, because the writer has employed a new mode of graduation which differs in principle from the known graduation and will be easier to apply than that.

PHYSICAL PART

I. FUNDAMENTAL PRINCIPLES

A. THE PERIODICAL VIBRATION

A simple example of a purely periodical vibration is a material point moving at a constant rate in a circle. If the movement of the point is projected on one of the diameters of the circle,



for example the X-axis, the simplest form of linear vibration is obtained.

The equation of the distance of the projection point P_1 from the equilibrium position (the coordinate zero point O) is:

$$x = a \cdot \cos \alpha$$

x is called the elongation (the displacement), the momentary value of the vibration. a is the amplitude, the maximal value of the vibration. α is the angle between the X-axis and OP.

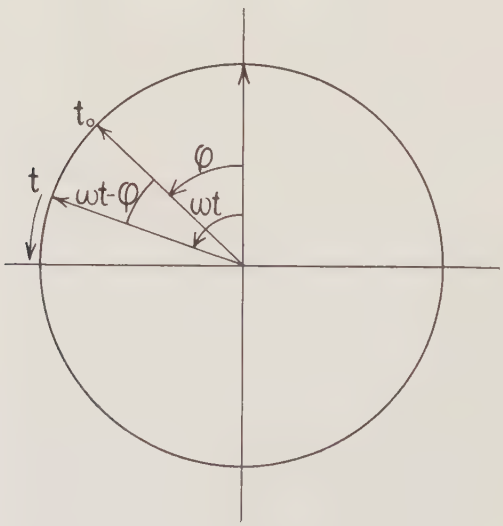
Supposing OP to have the shape of an arrow (vector) with its point turning round with an indifferently selected positive turning direction (usually anti-clockwise) with the constant angular velocity ω (ω^0 or ω radians in 1 second), the angle $a = \omega t$ is a measure of the time. The time T elapsing until the vector — after a single rotation — reaches its initial position is called the period of the vibration. The number of periods in the time unit $f = \frac{1}{T}$ is termed the frequency. The unit is 1 Hertz (Hz). The relation between the angular velocity ω and the frequency f is:

$$\omega = 2 \pi f;$$

If the observation of the vibration movement begins at the moment t_0 (from the commencement of the vibration in the equilibrium position), the vector will have described the angle $\omega t_0 = \varphi$. t sec. (after the beginning of the vibration), the vector from its initial position at the beginning of the observation will have described the angle $\omega t - \omega t_0 = \omega t - \varphi$, and the elongation will be

$$x = a \cdot \cos (\omega t - \varphi).$$

The angle $\varphi = \omega t_0$ is called the phase constant, and it expresses



how great a fraction of an entire vibration has been performed at the moment when the observation began. $(\omega t - \varphi)$ is called the phase.

B. THE VECTOR METHOD IN OSCILLATION PROBLEMS

On examining the relation between several sinus-shaped vibrating magnitudes with the same frequency the individual vibrating magnitude is characterized by a vector whose length is the amplitude of vibration, and which at the beginning of the observation forms the angle φ (= the phase constant) with a fixed axis, the "time axis". The vector is supposed to rotate with a number of vibrations per second corresponding to the frequency. Thus the vector itself is used as the symbol of the vibration, whereas the projection of the vector point on one of the axes will be the true picture of the straight-lined vibration.

The survey of the relation between several vibrating magnitudes is facilitated by using such a vector diagram. In practice it often is easier to treat them geometrically, as computation with the corresponding trigonometric magnitudes in several cases may lead to complicated expressions.

C. THE USE OF COMPLEX QUANTITIES

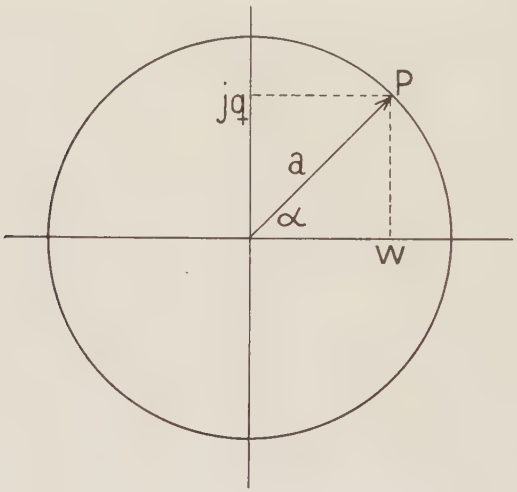
A possibility of arithmetical treatment of them is obtained by using the complex figures introduced into arithmetics for other purposes.

Mathematics distinguishes between two kinds of figures: real and imaginary figures. The unit of the imaginary figures is $\sqrt{-1}$; one solution of the equation $x^2 = -1$. This unit is designated with the letter i or, in order to prevent mistakes with the current (i) by comparison with the electricity rules, with the letter j. The complex figures are obtained by addition of real and imaginary figures. A complex figure may be represented graphically. The real figures are plotted along the axis of abscissae and the imaginary figures on the ordinate. The sections of determination for the vector point P will be w and jq respectively.

The point P thus represents the complex figure:

$$a' = w + jq = a \cdot (\cos \alpha + j \cdot \sin \alpha)$$

An apostrophe (′) by the side of a magnitude in the following means that it is complex. The numerical value a of



the vector is called the numerical value or module of the complex figure:

$$a = |a'| = \sqrt{w^2 + q^2};$$

The angle α is called the argument of the complex figure.

$$tg\alpha = \frac{q}{w}.$$

One of the advantages of this method at once becomes obvious, if a complex number is multiplied by $+j$ or $-j$. This implies a rotation of the vector by 90° in 1) positive and 2) negative direction respectively. The length of the vector remains unchanged. The two complex numbers will be: 1) $-q + jw$, and 2) $+q - jw$, since $j^2 = -1$.

The complex function $\cos \alpha + j \cdot \sin \alpha$ may also be written $e^{j\alpha}$. A multiplication by this magnitude thus means a rotation of the vector $\alpha^0 = \omega t^0$.

The elongation then becomes the real value of $a \cdot e^{j\omega t} = a \cdot \cos \omega t$. e is the base of the so-called natural logarithms.

D. DEFINITION OF THE IMPEDANCE

THE MECHANICAL IMPEDANCE

The definition of the mechanical impedance and the formal description used in the following are derived the most easily from the equation of motion of an elastically fixed, theoretically punctiform, mass.

If a sinus-shaped force: $K = A \cdot \cos \omega t$ is allowed to act upon this system, the point will perform forced vibrations. The equation of vibration expresses that the total of the forces acting on the point equals mass · acceleration. The forces opposed to the force K depend of the mass of the point (m), the stiffness (s), and the resistance (r). A is the amplitude of the force, ω is the angular velocity.

If all these vibrating magnitudes are regarded as vectors, and their arithmetical delineations are used as complex numbers, the vibration equation (presuming that the vibration is stationary) may be expressed in the following form:

$$\left[r + j \left(\omega m - \frac{s}{\omega} \right) \right] \cdot U' = A',$$

where U' is the velocity in complex form. Putting

$$r + j \left(\omega m - \frac{s}{\omega} \right) = w + jq = Z',$$

the equation becomes

$$Z' \cdot U' = A'.$$

This equation is quite analogous to Ohm's law (resistance · current = electromotive force (voltage), as force is analogized with voltage, and velocity with current. Z', which corresponds to the resistance, is therefore called the impedance which is the resistance in a circuit of alternating current.

The real part of the impedance $w = r$ is the mechanical resistance.

The imaginary part $q = \omega m - \frac{s}{\omega}$ is called the mechanical reactance and consists of mass and stiffness.

The mechanical impedance thus is the ratio of the driving force to the impressed velocity, both regarded as complex quantities.

The numerical value of the impedance is:

$$|Z'| = \sqrt{r^2 + \left(\omega m - \frac{s}{\omega}\right)^2}$$

Its phase, i. e. the phase lag between velocity and force, is determined by the equation

$$tg\,\varphi = \frac{\omega m - \frac{s}{\omega}}{r}$$

In case of resonance $\omega = \sqrt{\frac{s}{m}}$; $j\left(\omega m - \frac{s}{\omega}\right) = 0$, the impedance $= r$, i. e. real.

THE ACOUSTIC IMPEDANCE

In analogy to the mechanical impedance the acoustic impedance is defined as *the complex ratio between sound pressure and rate of volume displacement* ('Schallfluss'), where the rate of volume displacement = the particle velocity · the surface. Its absolute value is the amplitude proportion between sound pressure and particle velocity, its phase is the phase difference between them.

The acoustic impedance per unit of surface for a pure progressing wave, *i. e.* the sound resistance in a medium, is:

$z = c$ (the velocity of the sound) · ρ (the density of the medium).

For atmospheric air at 18 °C. these numbers will be:

$$c = 3.4 \cdot 10^4 \text{ cm/sec.}^{-1}; \qquad \rho = 1.2 \cdot 10^{-3};$$
$$\rho \cdot c = 40.8.$$

Sound pressure and particle velocity are everywhere in phase, i. e. in this case the acoustic impedance is real.

Units: 1 *mechanical Ohm* is the resistance in a mechanical system, when a force of 1 dyn gives rise to a velocity of 1 cm/sec.

1 *acoustic Ohm* is a resistance by which a pressure of 1 dyn/cm^2 elicits a sound current of 1 cm^3/sec.

Transition from mechanical to acoustic resistance is achieved by dividing the mechanical resistance by the square of the surface.

E. THE CONNECTION BETWEEN IMPEDANCE, REFLEXION COEFFICIENT AND THE CHANGE OF PHASE

If a sound wave meets a sound receiver, part of the sound energy will be absorbed by the receiver, another part will be reflected.

Reflexion coefficient means the ratio between the intensity of the reflected sound wave and the intensity of the incident wave (the energy-reflexion coefficient R). The amplitude-reflexion coefficient ($\sqrt{R}$) is the corresponding ratio between the amplitude (sound pressure) of the reflected and the incident wave.

Analogously the *absorption coefficient* (a) is defined as the ratio of non-reflected to incident sound energy (the energy-absorption coefficient), *i. e.*

$$a = 1 - R.$$

The acoustic conditions of the sound receiver are not characterized entirely by the determination of a, however. It is necessary also to know the *phase change* (ϑ) taking place at the receiver between the pressure of the reflected wave and the pressure of the incident wave.

By these two magnitudes: R (respectively $\sqrt{R}$ or a) and ϑ the acoustic conditions of the receiver and, thus, the impedance Z', are determined completely.

The relation between these magnitudes is given in the equation

$$\sqrt{R} \cdot e^{j\vartheta} = \frac{\frac{z'}{c \cdot \rho} - 1}{\frac{z'}{c \cdot \rho} + 1};$$

where R = the energy-reflexion coefficient.

ϑ = the phase difference between the reflected and the incident wave.

$z' = w + jq$ = the complex impedance which, with $c \cdot \rho =$ the wave resistance in air as unit, is written: $\bar{w} + j\bar{q}$.

The solution of the above equation gives:

The phase change (at z'); $\quad tg\,\vartheta = \dfrac{2\,\bar{q}}{\bar{w}^2 + \bar{q}^2 - 1}$

The energy-reflexion coefficient $R = \dfrac{(\bar{w} - 1)^2 + \bar{q}^2}{(\bar{w} + 1)^2 + \bar{q}^2}$

i. e. the energy-absorption coefficient

$$a = 1 - R = \frac{4\,\bar{w}}{(\bar{w} + 1)^2 + \bar{q}^2}.$$

If, in the complex plane, $\dfrac{w}{c \cdot \rho} = \bar{w}$ is plotted along the axis of abscissae, and $\dfrac{q}{c \cdot \rho} = \bar{q}$ on the ordinate, the curves $a =$ constant will form a group of circles with centre along the axis of abscissae, whereas the curves $\vartheta =$ constant will form a group of circles with centre along the axis of ordinates.

$\left(\text{Centre: } \dfrac{2 - a}{a},\ 0 - \text{Radius: } \dfrac{2\sqrt{1 - a}}{a}\right)$, and the curves

$\vartheta =$ constant: $\left(\text{Centre: } 0,\ \dfrac{1}{tg\,\vartheta} - \text{Radius: } \dfrac{1}{\sin \vartheta}\right)$.

The two groups of circles will intersect rectangularly.

The numerical value of the impedance will be the distance from the coordinate zero point to the point of intersection between the circles, whereas its argument will be the angle between this line and the real X-axis.

As w always must be positive, only a half plane will be used. Each of the two groups of circles will intersect one another in two points, the one point with positive, the other point with negative value of q, corresponding to the reactance being an inertance (+) or a stiffness (—). At phase differences of less than 180° the intersection points with positive values of q are used, and at phase differences greater than 180° the intersection points with negative values of q are used (see *V. Thorsen*). When the ear drums were measured, nearly all the phase differences were greater than 180°, that is why the quadrant with the negative values of q will chiefly be used (at the frequencies which will be used in the following) (see for example Fig. 14, p. 130).

F. THE ENERGY ABSORPTION BY A SOUND RECIEVER

The energy which is absorbed by a sound receiver following the rules for a diaphragm whose several parts vibrate with the same amplitude and phase, is

$$L = F \cdot U \cdot p \cdot \cos \varphi,$$

where L = the amount of energy absorbed,
F = the active surface,
U = the effective value of the particle velocity,
p = the effective value of the sound pressure,
φ = the phase difference between pressure and velocity.

(The formula is quite analogous to the formula for work per second (N) in an electric alternating current circuit, where $N = E \cdot I \cdot \cos \varphi$; E and I are the effective values of voltage and current, respectively; $\cos \varphi$ is the so-called power factor).

From the above formula is deduced, when the impedance of a surface measuring 1 cm² rectangularly to the direction of propagation is called $z = w + iq$, and the wave resistance in air as previously is selected as unit, that

$$L = F \cdot \frac{\bar{w}}{\bar{w}^2 + \bar{q}^2} \cdot \frac{p^2}{c \cdot \rho}$$

$\frac{\bar{w}}{\bar{w}^2 + \bar{q}^2} = u$ denotes the ratio between the amount of energy actually absorbed (i. e. regard being paid to the increase of pressure taking place at the tympanic membrane) and the amount which maximally might be absorbed (namely, if the impedance corresponded to the resistance for a pure progressing wave in air). u is called the transmission factor ("Übertragungsfaktor").

The absorption coefficient (a) on the other hand is the ratio between the amount of energy absorbed by the ear drum and the amount of energy tendered. The sound pressure corresponding to the amount of energy tendered is that pressure which the incident sound wave alone would produce at the ear drum.

The ratio $\sqrt{\frac{a}{u}}$ denotes the increase of pressure which takes place before the ear drum on account of the reflection from the drum. It varies between 1 (complete absorption) and 2 (complete reflection) (*Waetzmann and Keibs* 56).

If the curves u = constant are plotted in the same complex half plane as was used before, a group of circles will be obtained with center along the absciss axis $\left(\text{center: } \frac{1}{2u},\ 0 — \text{radius: } \frac{1}{2u}\right)$, i. e. all the circles will touch the zero point of coordinates.

In areas corresponding to numerically small phase differences the u-curves follow fairly closely the absorption curves. With increasing phase difference the course will deviate more and more. In those areas which will be used the most in the following, the changes in Abs. correspond to changes in the same direction of u, but particularly at the higher frequencies may be obtained considerable changes of the energy absorption, and even a change in the opposite direction in spite of constant absorption coefficent.

At the low Abs. (and minor phases) the Abs. and u increase in about the same proportion. Towards the high Abs. u increases far more rapidly than a.

Thus u is the correct expression of the amount of energy

absorbed and ought to be employed, if exact information is to be obtained about a difference or a change in the energy absorption. In the relatively low absorptions and small phases which will mostly have to be employed for ear measurings at 512 and 768 Hz., the Abs. coefficient may be used with approximation however.

G. THE EAR AS ACOUSTIC RECEIVER

Here only a few of the recent investigations will be mentioned, which are of importance for understanding the efficiency of the ear to absorb sound energy and to transmit the amount of energy received to the labyrinth.

Looked at from this viewpoint the middle ear is destined to adapt the Imp. against stapes vibrations in fenestra ovalis to the much smaller Imp. for the progressing wave in the air. By such an intermediate link a greater energy transport to the inner ear is obtained, because the maximum of energy transport from one system to another will be attained, when the Imp. of the two systems, looked at from the point of contact, is of the same range of magnitude.

v. Békésy has performed a series of examinations which show how the absorption of energy through the ear drum takes place, and how the previously already demonstrated transformation of pressure originates. In opposition to *Helmholtz, v. Békésy* shows that the whole tympanic membrane up to about 2400 Hz vibrates like a stiff surface involving the manubrium. Thereby the surface rotates round an axis located at the uppermost border of the tympanic membrane. The amplitude of vibration therefore becomes greatest beneath umbo at the border of the ear drum. This must require a special mobility of the ear drum in that place, and *v. Békésy* at the lowermost border of the drum actually finds a very mobile fold with a radius of curvature of about 0.5 to 0.8 mm. The great elasticity of this fold permits of a displacement of the conic part of the membrane without deformation worth mentioning. The conic shape contributes to the firm linkage between ear drum and manubrium mallei. Accordingly the

ear drum does not contribute to the transformation of pressure — as *Helmholtz* thought — beyond what corresponds to the proportion of surface between tympanic membrane and basis stapedis. On the other hand, more energy is transmitted than if the tympanic membrane were a tense membrane in which the manubrium was embedded.

v. Békésy calculates the magnitude of the transformation of pressure after that area of the ear drum which is in rigid connection with the manubrium, the surface of basis stapedis, and the lever effect of the auditory ossicles at a value of 22, finding about the same by measurings on fresh temporal bones with opened labyrinth.

Up to about 2400 Hz. the sound pressure is transmitted independent of the frequency, whereas the ratio between the vibration amplitude of basis stapedis and a constant sound pressure at the ear drum decrease with increasing frequency. In *v. Békésy*'s opinion this decrease of the stapes vibrations proportional to the frequency speaks for the friction power in the medial tone sphere being predominant in the movement of the auditory ossicles. This supposition too is in conflict with previous views. The border of stapes coalesces with the oval window by a very narrow membrane and can scarcely move more than 0.10 mm. Therefore it has always been assumed that stapes coalesced with fenestra ovalis by strong elastic forces, and that its displacements were determined by these forces. The forces of friction which *v. B.* attributes to the ear muscles form the internal resistance in the system auditory canal — tympanic membrane — stapes.

From stapes which thus vibrates with greater force, but with less amplitude than the malleus, the sound pressure vibrations are transmitted to the labyrinth against an external Imp. (when the labyrinth is regarded as a system linked to it) which depends of the perilymph and the elasticity of membrana basilaris and fenestra rotunda.

The Imp. measured in the auditory canal at the low and medium frequencies chiefly is an elastic resistance (*Tröger* 1930) essentially determined by the air cushion of the middle ear (*v. Békésy* 1936).

II. MEASUREMENT OF ACOUSTICAL IMPEDANCE

A. ELECTRO-ACOUSTICAL AND ENTIRELY ACOUSTICAL METHODS

Impedance measuring is a relatively new physical investigation method introduced for the determination of the acoustic properties of sound absorbing materials. The first quantitative measurings of acoustic Imps. were performed by *Kennelly* and *Kurokawa* in 1921 (cit. Stewart and Lindsay).

Many different methods have since then been employed for different purposes. Extracts of this purely physical and, for a physician, very complicated literature are outside the scope of this work, even though some of the methods have been used for measurements of the Imp. of the tympanic membrane.

It shall merely be mentioned that the ratio between pressure and velocity generally is not determined directly, but that other magnitudes are employed which may be determined more easily and more exactly, and the components of the Imp. are calculated from them.

The mechanical-acoustic changes may be converted into analogous electric changes by allowing the mechanical or acoustic impedance, which is to be examined, to react upon a known sound producer (telephone), and then measure the changes which thus take place in its resistance and reactance.

In other methods the telephone is merely used as sound producer, and the measurings are made for example as sound pressure measurings at first before the unknown resistance, subsequently with a known resistance substituted for the unknown one. In 1932 this method was by *v. Békésy* used for ear measurings, and in 1936 by *Keibs.*

In works published by *West* (1928) and by *Tröger* (1930), likewise treating of ear measurings, stationary waves were used in a pipe which was closed hard at first, and afterwards by the unknown resistance (*in casu* the ear). By sound pressure measurings information may in the two cases be obtained

about the condition of vibration in the pipe, and from it can be calculated the Imp. of the occlusion.

In all these methods the very measurings according to *Schuster* and *Waetzmann* are time-consuming and complicated, and the subsequent calculations, to judge from the literature, are exceedingly complicated.

Far plainer methods for determination of Imp. were suggested by *Schuster* in 1934 and by *Robinson* in 1937. Both these methods were originally indicated for the purpose of determining the sound absorbing efficiency of different samples of material. In 1938 *Waetzmann* performed measurings on ears with dimensions of the original apparatus adjusted for this purpose.

For this reason it was the most practical to employ *Schuster*'s method, even though it required fairly much purely physical work before measurings on ears could be proceeded to.

B. THE ACOUSTIC MEASURING BRIDGE

1. PRINCIPLE AND CONSTRUCTION OF THE ACOUSTIC MEASURING BRIDGE

The principle of the measuring bridge is analogous to the principle of Weathston's measuring bridge known from electrics, i. e. measurement of acoustic impedances by comparison.

The bridge consists of a pipe, the "main pipe", Fig. 1 (*OB*), the ends of which are closed by the two impedances which shall be compared (a variable "comparison resistance" and, *in casu*, the ear drum). In the main pipe, at a right angle to its axis, is fastened a telephone diaphragm (*M*) giving sound to both sides. On the main pipe are fixed two side-tubes. Their places of insertion in the main pipe (*C* and *D*) lie perfectly symmetrically in relation to the telephone membrane. The two side tubes are connected with a transverse pipe parallel with the main pipe. On the middle of this pipe is a discharge pipe (*A*), the "auscultation place". With the help of an *Y*-pipe

and two auscultation rubber tubes as intermediate links it is connected with the examiner's ears.

An alternating current generator supplies current to the telephone.

When the Imp. is equal in two planes lying symmetrically in relation to the telephone membrane, there will be an antinode at the auscultation place, because the sound waves coming

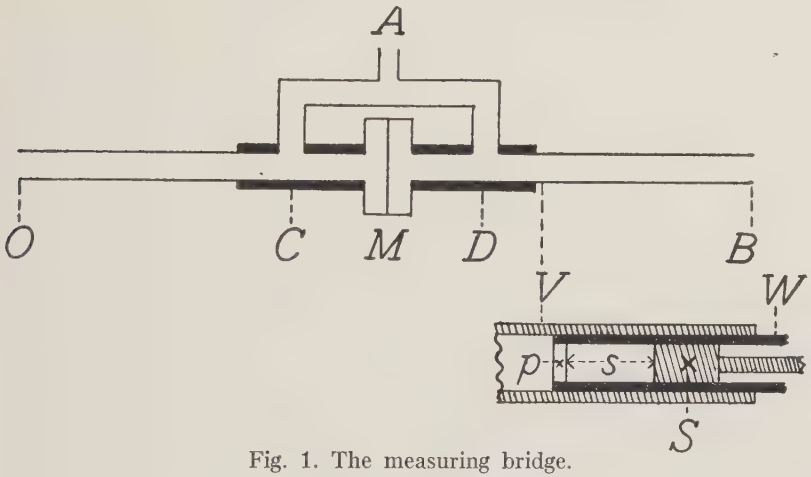


Fig. 1. The measuring bridge.
Nethermost: Right side of the measuring bridge + comparison resistance on an enlarged scale.

from the right and left side of the bridge will there meet with opposed phase and thus neutralize each other by interference. If the Imp. is not equal in symmetrical planes, this will not be the case.

Thus the examiner need only vary the resistance of comparison until the sound is minimal or disappears entirely. From the adjustment data of the comparison resistance it is possible to determine the Imp., as will be described later.

The comparison resistance consists of a felt plate (p) which is placed in the orifice of a pipe, the "felt pipe" (W), which can be inserted in and neatly fits the main pipe (V) of the measuring bridge. Inside the "felt pipe" W a metal piston (S) can be displaced by means of a bar so that the length of the air column (s) between the felt plate and the piston can be changed.

The impedance in a fixed plane (F) in the main pipe is determined by the reflection coefficient (R) and the phase change (ϑ).

By displacement of the total comparison resistance in the main pipe actually only ϑ in the plane F is changed.

By displacement of the piston in the "felt pipe", i. e. by a change of the distance s, both the reflection R and the phase change ϑ are changed for F.

The construction of the measuring bridge is described in *Waetzmann*'s work. An appropriate set of ordinary head telephone was employed, one of the membranes of which was removed. Its electromagnet + magnet case was placed on the free side of the other membrane. The magnet cases were perforated for the insertion of the main pipe.

The pipes were ordinary, serially manufactured brass pipes, but they were selected so that the pipe of the comparison resistances fitted as neatly as possible in the main pipe. The piston was about 4 cm. long and consisted of two brass bars screwed together with a leather safety device between them.

It is important to take care that the system, by closing the two ends of the main pipe and the side-tube, is perfectly airtight. On insertion of the comparison resistance there will occur an inevitable leakage, but that leakage was so small that it was necessary to make a small side-hole outside the auscultation place in order not to perform at any rate the greater displacements of comparison resistance and piston too slowly. For reasons which will be discussed later no lubricants were used.

In order to connect the apparatus with the ear it must be placed on a support adjustable in all three dimensions. It must be possible to perform the displacements with a suitable exact adjustment.

For patients in a dorsal recumbent posture the measuring bridge can be used standing horizontally, as was done in these examinations. For sitting patients it is convenient that the apparatus can be tilted a little round a horizontal axis also.

2. CALIBRATION OF THE MEASURING BRIDGE

The theory of the comparison resistance is discussed by *Schuster* and *Stöhr* to whose paper the reader is referred.

Among other things it is accounted for, when the physical properties of the absorbing substance is known, how the most favourable thickness of a given absorbing material can be calculated, namely, that thickness of plate, where the maximal absorption is 100 per cent. Generally there does exist a definite "most favourable thickness" for each frequency.

From the same properties of material the smallest measurable absorption occurring at the adjustment $s = 0$ can be calculated. It is cautioned against using plates of less than 1 mm. thickness, for they will give rise to vibrations of the plate exerting an untoward influence on the comparison resistance.

The constants of material, current resistance and porosity, which are necessary for finding the most adequate thickness of the felt plate (and the kind of felt) by calculation, not being known, the thickness which was used for the present examinations was found empirically. It was at the same time endeavoured to measure low absorptions which are of special interest for ear measurings.

a) *The graduation of the comparison resistance.*

After *Schuster* and *Stöhr* the calibration is performed by determining respectively a (the absorption coefficient), R (the intensity reflection coefficient) or $\sqrt{R}$ (the amplitude reflection coefficient) and ϑ (the phase change) as functions of s for each frequency.

The graduation can be done by an electro-acoustic method for measurements of impedances, but it can also be done with the help of the measuring bridge itself, the inlet impedance in hard-closed pipes of different length being used for comparison.

In a pipe of length L, closed by an impedance with the reflection R_2 and the phase change ϑ_2 the following holds for the inlet impedance in the orifice of the pipe (reflection R_1, phase change ϑ_1):

$$R_1 = R_2 \cdot e^{-4\beta L}$$

$$\vartheta_1 = \vartheta_2 - 2\,a\,L \pm 2n\pi; \quad \left(a = \frac{2\,\pi}{\lambda}\right), \tag{1}$$

where L = the length of the pipe.

n = an integer which is selected so that ϑ lies between 0 and 360°.

β = the pipe damping constant =

$$3.3 \cdot 10^{-5} \cdot \frac{\sqrt{\nu}}{A} \cdot (1 + 0.0012 \cdot t)$$

ν = the frequency.
A = pipe radius.
t = temperature in Celsius.

In the orifice of a hard-closed pipe the impedance becomes:

$$R_1 = e^{-4\beta L} \quad \text{or} \quad a_1 = 1 - e^{-4\beta L} \qquad (2)$$
$$\vartheta_1 = -2\,a\,L \pm 2n\pi.$$

On graduation of the comparison resistance the hard-closed "comparison pipe", which has the same diameter as the main pipe of the measuring bridge, is placed at the one end of the measuring bridge. The comparison resistance is changed until equilibrium is attained. Then the impedance is equal in planes lying symmetrically in relation to the center of the measuring bridge, i. e. the telephone diaphragm.

The distance from the hard closure of the comparison pipe to the center of the measuring bridge is called b, and the distance from the center of the measuring bridge to the nearest surface of the felt plate is called d. In case of complete symmetry of the bridge the inlet impedance of the felt plate is determined by:

$$R = e^{-4\beta(b-d)}$$
$$\vartheta = -2\,a\,(b-d) \pm 2n\pi \qquad (3)$$

Adjustment with balance between the two sides of the bridge is possible only for a number of definite values of s. That is illustrated by sketching the two impedances in a polar coordinate system by a change of respectively s and the length of the comparison pipe. The connection between R, ϑ and z' is expressed by the equation

$$\sqrt{R} \cdot e^{j\vartheta} = \frac{\frac{z'}{c\,\rho} - 1}{\frac{z'}{c\,\rho} + 1}.$$

It was previously used for graphic presentment of z', the real part and the imaginary part (w and q) being noted as Cartesian coordinates. When $\sqrt{R}$ is used as a radius vector and ϑ as polar angle, the same impedance half plane within the circle $R = 1$ is obtained.

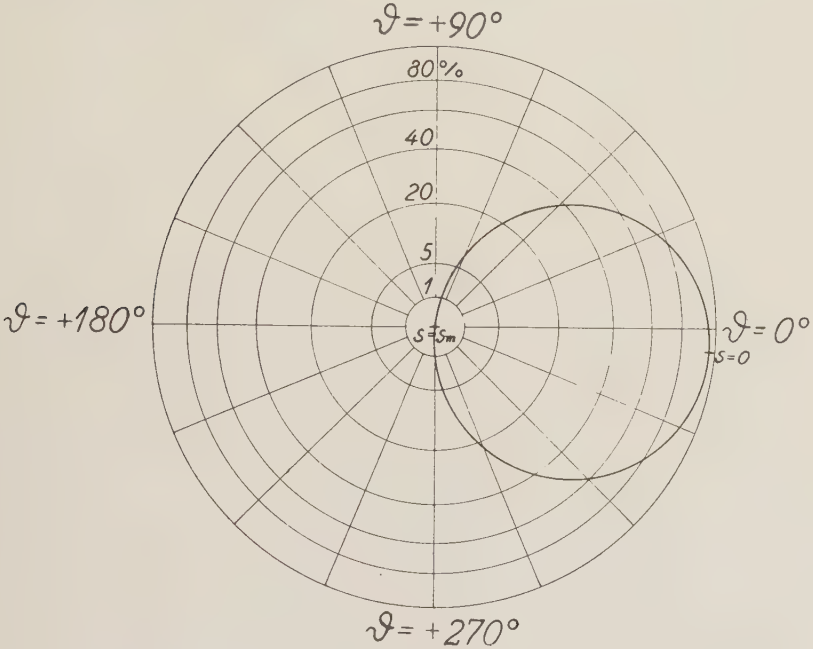


Fig. 2. The course of the impedance curve of the comparison resistance on change of length of the air column.
(After Schuster and Stöhr).

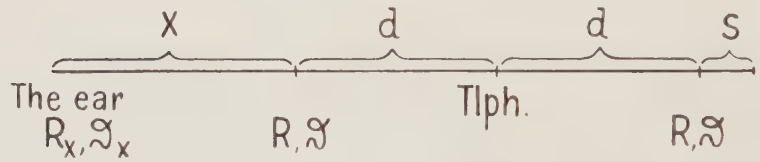
The impedance of the felt plate is with approximation a circle which, at $s = s_m$ (the greatest measurable absorption), passes through the zero point of coordinates and, at $s = 0$ (the smallest measurable absorption), almost touches the circle for $R = 1$. The impedance curve of the pipe is a spiral round the zero point of coordinates. Only in the point of intersection of the two curves is a compensation possible (Fig. 2).

Schuster and *Stöhr* thus determine the inlet impedance of the felt plate, i. e. R and ϑ in the plane of the felt turning towards the center of the bridge as a function of s. Presupposing complete symmetry of the measuring bridge the graduation

was performed for the very comparison resistance and may be used in another measuring bridge — under the same presupposition.

By measurement on an ear s and d are determined. From s are found R and ϑ on the curve. With the help of d the tube (x) is found, the inlet impedance of which is (R and ϑ) when it is closed with the impedance of the ear. According to the formule (1) (p. 33) this is:

$$R_x = \frac{R}{e^{-4\beta x}};\ \vartheta_x = \vartheta + 2\alpha x \pm 2n\pi.$$



b) *Graduation of the measuring bridge.*

In the present work the graduation was performed in a way differing somewhat from the abovedescribed, namely, not after the comparison resistance, but it was connected with a definitely fixed plane in the measuring bridge itself, the "measuring plane".

As comparison pipe was used a pipe, 1 meter long, with a displaceable brass piston. At the highest absorptions a pipe of 1 or 2 meters' length was inserted between this pipe and the measuring bridge. The graduation was commenced with a low d-value and the shortest pipe length, where a compensation is of interest, namely, corresponding to a length of $b - d$ of about $\frac{\lambda}{2}$. As the comparison pipe (b) is made longer, d must also be made greater in order to insure compensation, through which ($b - d$) becomes constant. It is thus the same piece of pipe whose absorption is measured, and only the phase in proportion to a fixed plane in the measuring bridge is changed. If b is gradually made greater, and it is impossible to increase d any more on account of the dimensions of the measuring bridge, a compensation is not possible until ($b - d$)

becomes $\frac{\lambda}{2} \cdot 2$; at the same time s must be made greater, as the absorption now is measured in the double piece of pipe. d is made small, and the graduations are made as before, b being made longer. The same is repeated for $\frac{\lambda}{2} \cdot 3.4$, etc.

A compensation between the two sides of the measuring bridge is possible only when $(b - d) = 0$ or $\frac{\lambda}{2} \cdot n$ (where n

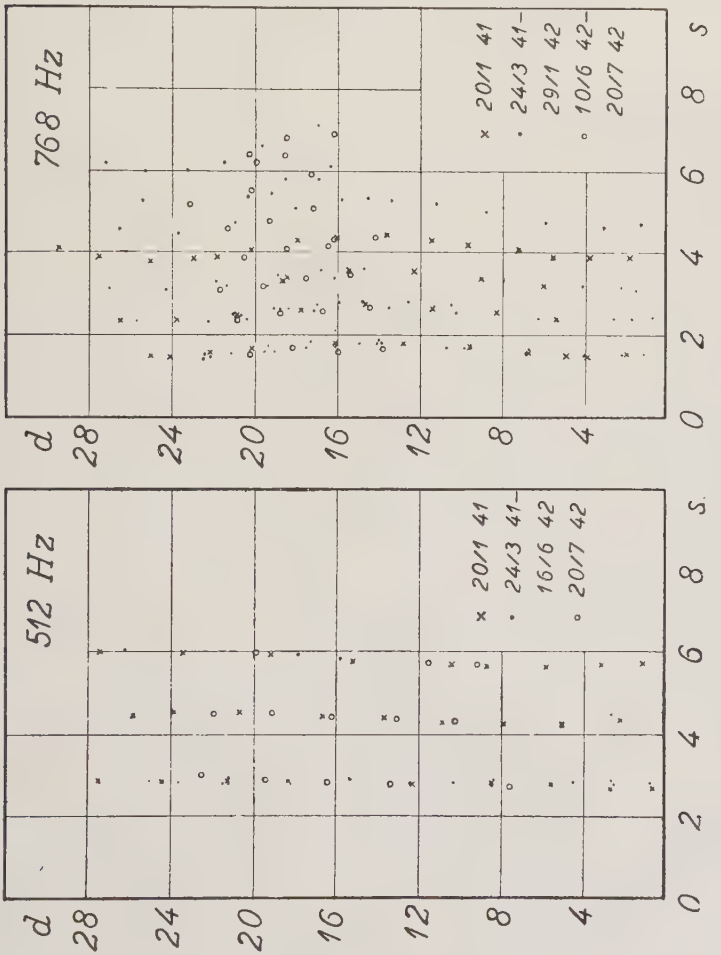


Fig. 3. The variation of d and s, when the length (b) of the comparison pipe is changed. 512 and 768 Hz.

is an integer), for only if this is the case, the sound waves coming from right and left will reach the listening place with a phase difference of 180°, and thus compensate each other. The different values of s and $(b - d)$ belonging together, which are found in this way, correspond to the number of solutions s_n and $(b - d)_n$ obtained, if the equations (3, p. 34) are regarded as determination equations for s and $(b - d)$ (as R and ϑ are functions of s) at the different values which n may assume.

On change of s both absorption and phase, as mentioned, are changed. $(b - d)$ does not become exactly 0 or $\frac{\lambda}{2} \cdot n$, because the phase change, which occurs at the felt plate, is compensated by a change of d.

In graduating the measuring bridge in this way a number of homogeneous values of b and d are obtained for each value of s, where $(b - d)$ constantly is about $\frac{\lambda}{2} \cdot n$ (Fig. 3). For the low frequencies (384 and 512 Hz.) s is also constant for each value of $(b - d)$ (Fig. 3 a). For the higher frequencies, however, s varies a little at the same time as b and d change (Fig. 3 b) without it being possible to find out why.

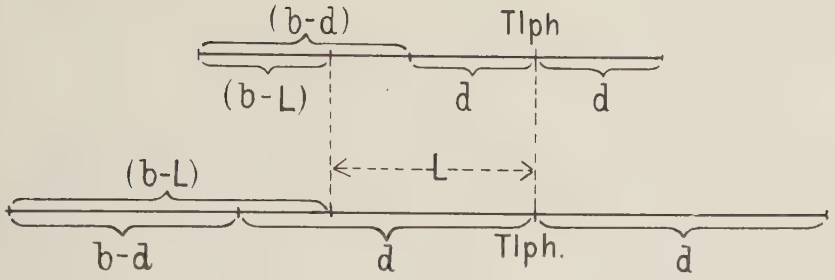
For each value of d and s phase difference and absorption are calculated in a plane lying 3.4 cm. outside the orifice of the left side of the main pipe. If a 3.4 cm. long olive later is used in ear measurings, a and ϑ are determined directly at the orifice of the olive.

Calculation of the Phase.

For each value of d and s the phase was calculated after the formula:

$$\vartheta = - \frac{2 \cdot (b - L) \cdot 360^\circ}{\lambda} \pm 2n\pi,$$

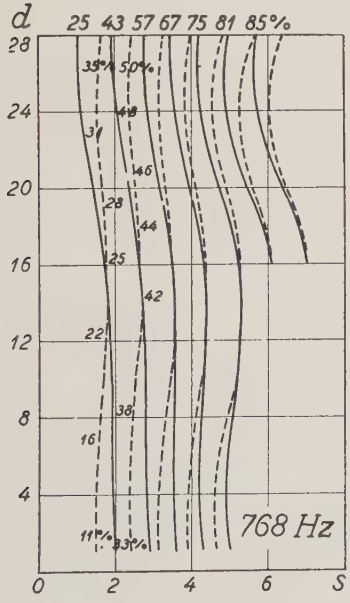
where L is the distance from the telephone diaphragm to the orifice of the 3.4-cm. pipe ("the measuring plane").
The phase difference between the reflected and the incident wave in the fixed plane will, with negative sign, be increasing,



if b is increased. The two drawings show how the theoretical piece of pipe $(b - d)$ is displaced outwards. If the phase difference is called negative or positive according as it is greater or smaller than 180°, it will be seen that, when d is a little smaller than L, it is positive, becoming, if it is $= L$, about 0° or $360° \cdot n$, and subsequently negative etc.

Calculation of the absorption.

The absorption is calculated analogously with the phase difference of $(b - L)$ for each homogeneous value of d and s.



By interpolation it is then possible to plot a number of isoabsorption curves (Fig. 4), i. e. curves with the same absorption in the fixed plane in the measuring bridge at different values of d and s. A variable impedance is thus imagined to be placed in the plane, the absorption is kept

Fig. 4. — — — —: Isoabsorption curves with the same absorption at the felt plate. The numbers along the dotted curves indicate absorption in the pipe $(b - L)$ calculated to the "measuring plane". — ————: Isoabsorption curves with the same absorption in the "measuring plane" plotted by interpolation between the absorptions calculated from $(b - L)$.

constant and the phase is changed. The curves are selected so that the absorption which they represent is the absorption in the piece of pipe $(b-d) \cdot n$. These curves will thus intersect the originally plotted curves (Fig. 3) at the value of d which is $= L$.

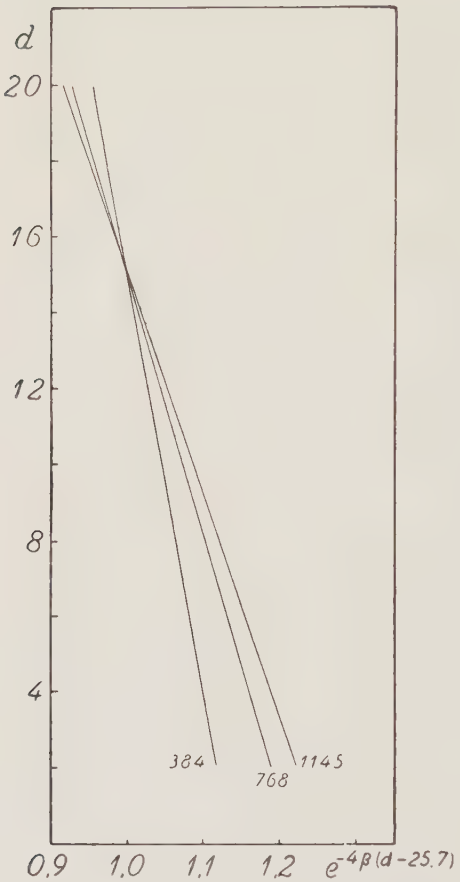


Fig. 5. Correction to the measuring plane ($R_{corr.}$) of the absorption (the reflection R) in the plane symmetrical with the felt plate. This correction will — provided that the symmetry of the bridge is accurate enough — afford the same result as the plain curves (Fig. 4).

These curves (Fig. 3) plotted directly at the measurings are also isoabsorption curves in so far as they denote the absorption at the felt plate — or the absorption at the orifice of the pipe $(b-d)$ lying symmetrically with it; in proportion to a definite plane in the measuring bridge, however, the absorption differs very greatly at a low and at a high value of d.

These curves can also be used when the absorption is corrected with the absorption in the pipe $(d-L)$. That is done after the formula:

$$1 - a_{corr.} = R_{corr.} = R \cdot e^{-4 \cdot \beta \cdot (d-L)}$$

since $R = e^{-4 \cdot \beta \cdot (b-d)}$;

$$R_{corr.} = e^{-4 \cdot \beta \cdot (b-L)}.$$

Fig. 5 with the frequency as parameter shows the proportion between d and the correction factor $e^{-4 \cdot \beta \cdot (d-L)}$.

There is a difference of principle between the two methods

of plotting the isoabsorption curves. In both cases the original curves (Fig. 3) are started from. In the first case they are interpreted as curves with the same absorption at the felt plate and the plane lying symmetrically with it in the bridge. Therefore, in order to get the absorption in the measuring plane, they must be corrected with the absorption in the pipe ($d - L$). In the second case the curves directly represent the increasing absorption in the pipe ($b - L$) (in the "measuring plane" at the orifice of L) in proportion to d and s, and the isoabsorption curves are calculated by interpolation between these curves.

The latter method has the advantage that the magnitude d has not been utilized in calculating the absorption, whence the graduation has been made independent of eventual inaccuracies in the symmetry of the bridge. The graduation of the comparison resistance conveyed to the plane of the felt plate has the advantage that a parallel can be drawn with the graduation performed after electro-acoustic methods, as was originally done by *Schuster*. Here the absolute symmetry of the measuring bridge is of the greatest importance.

If the absorption is not calculated to the measuring plane, the error, considering the dimensions of the measuring bridge, may become about 14 per cent and about 17 per cent for 512 and 768 Hz. respectively (calculated according as d may become about 15 cm. greater and about 15 cm. smaller than L).

As the range of measuring in ear measurings, owing to the dimensions of the measuring bridge, lies with values of d in the vicinity of L — at 512 Hz. d is from 2 to 6 cm. greater than L, and at 768 Hz. from 1 to 5 cm. greater than L — the change in the absorption becomes but slight, for 512 Hz. about 4 per cent at the highest, for 768 Hz. about 5 per cent at the highest (cf. the correction factor, Fig. 5). For these frequencies this was paid no regard to, because the error introduced thereby is so small that it plays no rôle in ear measurings. The same holds for 384 Hz.

At the higher frequencies with the smaller wave length compensation may in two or more places be obtained with the

same magnitude of b, namely, at d and $d + \frac{\lambda}{2} \cdot n$. Measured at the felt plate the absorption differs $\left(\text{the absorption in the pipes } \frac{\lambda}{2} \text{ or } \frac{\lambda}{2} \cdot n\right)$, but on correction to the measuring plane at the orifice of the measuring bridge, or calculated to it after $(b - L)$, the absorption is the same, as b is constant.

Using, at 1145 Hz., the adjustment area with the smallest value of d, where compensation is possible, and where the adjustment succeeds best, the correction factor (see Fig. 5) in ear measurings becomes so great that it is necessary to reckon with it. The difference between d and L becomes about 10 —14 cm.

c) *Range of frequency of the measuring bridge.*

Unfortunately the range of frequency serviceable for measuring is very limited. The lower limitation is due to the increasing wave-length, while above — at 1200-1300 Hz — the adjustment itself commences to be difficult, presumably on account of leakage between the adjustable parts and also because of the steadily increasing overtones.

Schuster was able to use even 1536 Hz; and, by modifying the bridge, Menzel was enabled to use frequencies as high as 3500 Hz., but at the same time he gave up determination of the phase.

In the following examinations the frequencies

384, 512, 768, and 1145 Hz.

were used, the last-named being used, because the frequency 1024 was not applicable on account of the conditions of resonance in measuring bridge and side-tubes.

d) *Interpolation and difficulties of adjustment to small absorptions.*

Interpolation at small absorptions.

As was mentioned, equilibrium between the two sides of the bridge only can be obtained, when $(b - d) = 0$ or about

$\frac{\lambda}{2} \cdot n$. The lowest absorption corresponding to this, namely, about $\left(1 - e^{-4 \cdot \beta \cdot \frac{\lambda}{2}}\right)$ for the 4 frequencies 384, 512, 768, and 1145 Hz. are respectively about 32 %, 30 %, 25 %, and about 20 %. Absorption values below these must be judged with the help of an interpolation from the immediately following higher absorptions, where a compensation is possible, i. e. corresponding to $(b - d) =$ about λ, to which correspond the absorptions: about 54 %, 50 %, 43 %, and about 36 %. Therefore the interpolation curves were plotted corresponding to about 10 %, 10 %, 7 %, and about 4 %, respectively.

Thereby an error is introduced, which becomes greater and greater the lower the absorption becomes. Especially on examining ears with conduction affections very small absorptions are always found at the low frequencies. The writer nevertheless thought it would be of some interest to record these values instead of noting for example 'less than a certain value', because they convey an idea of the relative proportion between the absorptions. The measuring itself is indeed accurate, but the small absorptions found by interpolation may be encumbered with considerable errors.

Difficulties of adjustment to small absorptions.

With a comparison resistance the felt plate of which has the "most favourable" thickness there may arise difficulties of adjustment in measuring resistances with low absorption (below about 20 per cent).

As mentioned, a minor plate thickness was selected for the ear measurings described in the following. This difficulty of adjustment does still occur however.

Schuster and *Stöhr* have treated it thoroughly both in theory and in practice: If the adjustment is made by changing s and d (displacement of the piston in the felt pipe and the felt pipe in the main pipe respectively) it is seen that a fairly pronounced minimum can be obtained not only by a single adjustment (s, d), but by a whole series of coupled values (s, d) lying close together, whose sum $(s + d)$ constantly has the same value however. At the different adjustments the position of the piston in the main pipe thus remains unchanged.

This is explained by the course of the impedance curve of the felt plate on changing s (Fig. 2, pag. 35). In case of very high absorptions the course of the curve is radial. A change of s means a change of a without change of ϑ. At small absorption it is almost the reverse. The course of the impedance curve being almost tangential, a change of s means a change of ϑ almost without change of a. Assuming that the correct adjustment of s and d has been found, a change of d will change the phase in a fixed plane in the main pipe. This phase change can be abolished again by changing s without any essential change of the absorption. Thereby it is possible to obtain a series of adjustments (s, d) at the low absorptions.

The difficulty is avoided and the correct adjustment is found by displacing the felt pipe, whereas the piston is kept fixed in relation to the main pipe. In case of small values of s — in a fixed plane in the main pipe — such a displacement will practically only give rise to a change of a. In order to obtain complete compensation it thereafter is necessary — for changing the phase — to displace either the piston with fixed felt pipe or felt pipe + piston. In this way a good compensation can always be obtained.

e) *Sources of error in measuring constant impedances. The connection with the measuring bridge.*

The airtight connection between impedance and measuring bridge is the first condition for obtaining applicable measuring results. Small untightnesses will cause great changes of absorption and phase, and completely compromise the results.

The frequency.

The importance of the frequency on calculation and measurement of the impedance in the orifice of a pipe hard-closed at the other end (the comparison pipe) is evident from the employed formules (p. 34). *The phase difference* in the orifice of the pipe is $-\frac{2 \cdot 360° \cdot L}{c} \cdot f \pm 2n\pi$. The Phase is a linear function of the pipe length or the frequency, when one of these magnitudes is kept constant.

At the greater pipe lengths there is a question of not quite negligible phase changes, when the frequency by more than a few Hz. deviates from the frequency reckoned with. At a pipe length of 100 cm. and a change of frequency of 5 Hz. for example the phase change amounts to about 11°.

The absorption (or the reflection) is calculated from the formula 2 (p. 34). Here the square root of the frequency is comprised in the pipe damping constant β, and the influence of a change of frequency is attenuated accordingly. By calculating the absorption in a pipe closed as above-described and 100 cm. long, the following figures are obtained:

512 Hz. $a = 63.9\,\%$,
502 Hz. $a = 63.4\,\%$,
522 Hz. $a = 64.1\,\%$,

that means to say that the change in the absorption is less than 1 per cent at a change of the frequency of 20 Hz.

The change of absorption in case of frequency fluctuations thus being minimal, the change of phase is so considerable that the exact adjustment of the generator is absolutely necessary. The generator was tuned with the help of tuning-forks, and will be discussed in detail under "The procedure in measuring" (p. 71).

The temperature.

The room temperature enters into the velocity of sound, which is used for calculating the phase difference, as well as in the pipe damping constant employed in calculating the absorption.

The phase difference. The velocity of sound increases with the square root of the temperature after the formula:

$c_T = c_0 \cdot \sqrt{\frac{T}{273}}$, where T is the absolute $tp. = T + 273\,°\mathrm{C}$.
c_0 is the velocity in air at $273° = 0\,°\mathrm{C}$.

Therefore, as the wave length changes with the temperature, it is necessary to calculate the phase at a definite, fixed temperature, which was selected to be 18°C. All the subsequent

measuring results thus refer to the phase difference in the orifice of hard-closed brass pipes at 18 °C.

In case of small pipe lengths fluctuations of temperature will only cause small changes of phase, but in case of pipe lengths of 1—2 m. a fairly considerable error will arise at the higher frequencies, if the adjustment is performed at one temperature and the phase is calculated after another temperature.

The graduation of the measuring bridge was carried out in a room, where the temperature fairly constantly was about 18 °C., but it was not controlled at each graduation. For the great pipe lengths a mean curve was used, for the smaller pipe lengths the curves were practically equal.

With another measuring bridge than that which was used here a graduation with 779 Hz. was performed at 15, 18 and 21 °C. The measured values of d correspond exactly to those calculated from the difference in the wave length. The difference between d at 18 ° and respectively at 15 and 21 °C. amounts to 1 mm. at the shortest pipe length, whereas, at the greatest pipe length used $\left(\frac{\lambda}{2} \cdot 8\right)$ it amounted to 9 mm. corresponding to a phase difference of 2 ° and about 15 °, respectively.

In ear measurings in which the pipe length does not exceed 25.7 cm., the change is so small that it is of no importance. Even if the air column in the pipe were assumed to be heated from 17 ° to 35 °, which naturally cannot be done in the brief space of time required for measurings, the change for 512 Hz. will only amount to 6 °.

The absorption changes with the temperature which is included in the pipe damping constant. The change is so small, however, that it is without importance even in case of greater pipe lengths and greater changes of temperature. For a pipe length of 100 cm. and 768 Hz. the absorption at 18 °C. is 71.0 %, at 35 °C. it is 72.2 %, i. e. the difference is no more than about 1 %.

f) *The accuracy of measuring and the reproducibility of the measurings during fairly long periods.*

The accuracy of measuring.

The preciseness of adjustment and, consequently, the accuracy of measuring are very great. In case of measuring constant impedances (in experimental arrangements) lying within the measuring range of the apparatus, an adjustment will nearly always be found, where there is perfect silence or where only the first overtone is audible. A change of the position of the piston (*s*) or, particularly, of the position of the felt pipe (*d*) of less than 1 mm. immediately gives rise to a distinct tone.

Readings are made with an accuracy of 1 mm.

As constant impedances were used pipes with felt plate and piston constructed as the comparison resistance, or pipes closed with a plate in which was bored a small hole.

Numerous series of 10 measurings each were performed, and prior to every measuring felt pipe and piston were reconveyed to the zero-position, and the frequency was gauged. The difference in the absorption between the measurings has been less than 2 per cent, and the difference of phase at 512 Hz., less than 1°.

How precise the adjustment can become appears from the subjoined numbers recorded for *d* and *s* (at 512 Hz.). As there was no graduation on the bridge itself, the size was measured with a scale.

d (cm.)	*s* (cm.)	*d* (cm.)	*s* (cm.)
18.2	3,1	18.3	3.0
18.2	3.1	18.3	3.1
18.2	3.1	18.3	3.1
18.3	3.0	18.3	3.1
18.3	3.1	18.3	3.1

The constancy of the comparison resistance.

The constancy of the measuring bridge, i. e. of the comparison resistance through longer periods appears from the measurings which were used at the graduation of the comparison resistance. From Fig. 3 a and Fig. 3 b pag. 37 it is directly

seen that the absorption practically persists unchanged throughout a period of 18 months. Variations of phase are not to be seen on the figures, for with regard to the curves running a straight course the points are only displaced along the curves. Measurings performed at different times have disclosed small variations of phase, which may be explained by changes of temperature. In the more oblique curves plotted for the high absorptions (81 and 85 % at 768 Hz.), where the changes of phase occurring on changes of temperature are greatest, this will also manifest itself in the absorption. The greater dispersion of the measurings here is probably due to this.

Schuster and *Stöhr* report that the absorption of a comparison resistance, which they used for several years, gradually changed in a definite direction. It was tested on different unchangeable resistances for 6 months. During that period a change of about 4 per cent was noted.

They are of opinion that this is due to oil vapours from the lubricant condensing in the pores of the felt and thus changing the porosity of the felt or the current resistance.

That is the reason why no lubricant was used during the period in which the recorded measurings were performed, nor was any change of the absorption found.

CLINICAL PART

INTRODUCTION

The importance of Imp. measuring in the otological clinic.

Knowledge of the Imp. of the ear drum is of importance for the solution of 2 questions, which have not been touched in this paper. The first is the *determination of the sensibility of the ear* in an absolute measure (cf. Waetzmann and Keibs 1936) where it is necessary to know the increase of the sound pressure due to the reflection from the drum (p. 26). The second is the *construction of electrical hearing apparatus*, where the relation between the acoustic Imp. of the telephone and the Imp. of the meatus and drum is of importance for the amount of energy which can be transmitted to the ear (p. 27). In both cases it is the very Imp. measured in the meatus which is of importance. It is mainly in order to be able to solve these two problems that the physicists have been interested in the measuring of the Imp. of the ear drum.

The conditions are different at the solution of the problem in question, which is of special interest to the otological clinic, where attempts are being made from the measured Imp. to come to some conclusion regarding the *vibration faculty of the sound conducting apparatus* under normal and pathological conditions.

What information about the sound conducting apparatus may be expected to be obtained by determination of the Imp. in a definite plane in the meatus?

Apart from the effect of the section of the meatus which is situated between "the measuring plane" and the drum, the measured Imp. is directly dependent on the Imp. of the very ear drum and more indirectly on the vibration faculty of the whole sound-conducting apparatus and is determining the quantity of sound energy which the ear drum is able to absorb.

Direct information can only be obtained about the vibration faculty of the ear drum + the factors on which it in its turn is dependent. The Imp. of the ear drum is essentially influenced by the air cushion in the middle ear, but it also depends on the auditory ossicles, because the greatest part of the ear drum, as mentioned, follows the manubrium mallei as a stiff plate (after *v. Békésy* (1941) 55 mm^2 against a total drum surface of 85 mm^2).

The utilization of the measured Imp. for the judgment of the vibration faculty of the sound conducting chain is made still more difficult because of the remaining part of about 30 mm^2 which does *not* vibrate as a stiff plate. This applies to membrana flaccida, on account of which *v. Békésy* (1941) is of the opinion that one cannot from the Imp. in the meatus draw conclusions regarding the movements of the manubrium. Furthermore the moveable fold at the border of the drum, described by *v. Békésy*, which normally allows the stiff cone-shaped part to vibrate as a whole, must be able to continue to carry out vibrations, and thus absorb sound energy even when the malleus and thus the cone-shaped part of the ear drum under pathological conditions is completely fixed in an intermediate position.

Still more indirect, of course, will the conclusions be from the Imp. of the ear drum to the energy transmission to the labyrinth. A part of the energy quantity passing through the ear drum will be absorbed in the middle ear and the adjoining air-filled cells, another part will be used up in another manner on its way to the internal ear, f. i. by the mentioned frictional resistance. The Imp. measuring gives no information as to how great a part is lost in proportion to the energy quantity which reaches the labyrinth.

It is reasonable to assume that pathological or experimentally produced changes in the sound conducting apparatus will influence the Imp. of the drum in a higher degree the nearer they are situated to the ear drum, most of all when they are situated in the drum itself or if they, as f. i. changes of the air pressure in the middle ear, directly influence the whole ear drum surface.

Changes in the ear drum itself will certainly most often cause a decrease of the mobility. Just the mentioned fold downward is often the seat of thickenings or calcifications, while the ear drum otherwise may be normal. Through a decrease of its elasticity the ear drum is prevented (after *v. Békésy*) from moving as a stiff cone, it will vibrate as a tense membrane. A greater part of the incident sound wave will be reflected and less energy will be transmitted to the ossicular chain with a reduction of hearing as a consequence. The same change of the mode of vibration of the ear drum will take place on changes of the air pressure in the middle ear. By changes of the air pressure in the meatus *v. Békésy* finds a reduction of hearing corresponding to the increase of the Imp. In case of changes of the air pressure in the middle ear the membrana fenestrae rotundae and basis stapedis, certainly are also influenced, but the force on the much larger ear drum surface must be predominant, so that there is reason to assume that the effect will be the same regardless of which side of the ear drum the pressure acts upon.

It might be anticipated that it would be possible also to obtain a change of the Imp. of the ear drum without influencing the energy supply to the labyrinth, namely, if only the energy quantity, which anyhow is lost in the middle ear, was changed f. i. by changes in membrana flaccida. It will at any rate be difficult to demonstrate a change in the subjective sound impression corresponding to a minor change in the Imp. In practice, however, the subjective sound impression alone may still give information about the transmission of sound to the labyrinth. It changes approximately to a logarithmic scale when the sound intensity changes lineally. Even to considerable changes in the linear measure — Abs., only small changes in the logarithmic measure — *db* will thus correspond.

An idea of the relation between the change in the Imp. associated with pathological changes in the ear drum itself and the energy transport to the labyrinth may be obtained by examinations made concerning the relation between the changes of the drum and the audition. In a material consisiting of 63 histopathological examined ears where the hearing was found

to be normal, i. e. all the tones were heard at an intensity of less than 20 *db* shortly before death *Polvogt* in 40 % found changes of the ear drum varying from slight thickening to marked calcification and from moderate to extreme retraction, with the drum adhering to the promontorium. It is improbable that f. i. the last mentioned change would not give rise to a considerable change of Imp., with a decrease of Abs. The hearing is reported to be normal, but with the fixed limit there may in single cases be a loss of hearing up to 20 db. *Polvogt*'s material thus shows, even if the hearing is normal or only slightly reduced, that there may in a great number of cases be found changes of the ear drum which in some cases are of such a character that they must be assumed to have caused considerable changes of the Imp. of the drum. A decrease of the absorbed energy quantity of 20 db in logarithmical measure corresponds to a decrease of from 100 % to 1 % in the linear Abs. measure.

Reduced elasticity of the ear drum caused f. i. by great flaccid cicatrices may in some cases be assumed to give an increased Abs. simultaneously with a decreased energy transmission to the ossicular chain.

Perforations in the ear drum will, as already *Lucae* has shown, completely change the acoustic conditions, so that one cannot predict anything about the Imp. measured in the meatus.

On pathological changes in the ear drum itself one must therefore probably expect most often to find a low Abs. when the hearing is reduced, but also in certain cases without any hearing loss or at any rate when it is impossible to demonstrate with the ordinary clinical audiometry.

Pathological changes in the middle ear mostly are of an inflammatory nature and will usually, if they attack the ossicular chain or inhibit its movements, cause a hearing reduction which is correlated to the pathological changes (*Polvogt* and *Bordley*). If also the ear drum is pathologic, which it often is, parallel with changes of the middle ear (*Ciocco*), one may expect in accordance therewith to find less energy passing into the ear and reduction of hearing in most cases.

It is more difficult to asume what will happen when the

ear drum is normal but the energy transport to the labyrinth is reduced f. i. by a stapes fixation. That the Imp. of the drum must increase is certain but to what extent the increase will assert itself in the measured Imp. will, as mentioned, depend on those parts of the ear drum which do not follow the sound conduction chain as a stiff plate. About that nothing can be said beforehand, but it must be kept in mind that changes in the energy quantity absorbed will assert themselves more distinctly at the Imp. measuring than at the examination of the hearing.

From the above it is seen how complicated the conditions are, especially as it is of importance to be able to demonstrate just conduction affections associated with normal ear drums. If the two possibilities occur — namely — change of the Imp. of the drum without change of the energy supply to the labyrinth, and change of the energy supply to the labyrinth without any change of the Imp. of the ear drum, to any great extent, the Imp. measuring in the meatus will be of no, or but slight value for the diagnosis of sound conduction affections.

III. PREVIOUS EXAMINATIONS IN THE MOBILITY AND VIBRATION FACULTY OF THE SOUND-CONDUCTING APPARATUS ON THE LIVING EAR

A. THE OTOLOGICAL LITERATURE

Numerous examinations of the entire sound conduction apparatus as well as of its single parts have been performed by animal experiments, and on preparations of human ears. *Dahmann*'s great and detailed work may be characterized as the last experimental work in accordance with the old school, i. e. before the advancement of physical acoustics was utilized in physiological acoustics.

Examinations of the living human ear have also been made

by several investigators with observations and records of the movements of the ear drum on severe changes of the air pressure in the meatus as well as on account of sound waves. The different methods which have been used are described in different manuals, f. i. by *Schaefer* and *Giesswein*, *Schaefer* as well as in more recent papers by *Frenckner* 1939.

Frenckner himself describes two methods for the examination of the mobility of the ear drum. The one consists of cinematographic registration of the movements of tympanic membrane and manubrium on alternating compression and rarefaction of the air in the meatus with the aid of a rubber balloon. In the other method tones are used, and the amplitude of the vibrations of the drum is calculated with the aid of the induced changes of electric tension in a small coil which vibrates in a magnetic field. The coil with the aid of a very fine glass tube is connected with the place of the drum to be examined.

The first method affords some information about the mobility of the ear drum, which does not, however, permit of drawing conclusions as to the conditions in sound vibrations. The second method has the great advantage of making it possible to determine the amplitude of a certain, isolated point, f. i. on the manubrium mallei. It affords the possibility of determining the mechanical Imp. of the manubrium itself, if the acting force, i. e. the sound pressure on the active drum surface, can be determined at the same time (which, by the way, is not done by Frenckner). The drawback of the method is that the examinations are not performed under physiological conditions, and that it is not suitable for clinical examinations.

Examination of the ear drum with the aid of Siegle's otoscope — eventually with *Holmgren*'s modification with observation of the manubrium between 2 hairs placed close to each other on either side of the centre of the lumen — is as far as I know, the only method for valuation of the mobility of the tympanic membrane and manubrium which has gained ground in the clinics.

It is also the only method which is mentioned by *Brühl* in the chapter: "Anamnese und klinische Untersuchungsmetho-

den" in *Denker* and *Kahler*'s manual besides the observation of the drum under air douche.

The only paper from the older clinical otological literature which directly treats of the impedance of the ear drum, naturally without defining it, was written by *Lucae* in 1867.

Lucae first shows that there is a sound reflection which takes place from the drum and which increases when the tension of the sound conducting apparatus increases. After that he compares the sound reflection from the right and left ear and thus obtains an objective expression of in which ear the absorbed quantity of sound is greatest.

These problems are solved with the aid of a T-formed tube construction where the side-tube acts as a Quincke interference tube, i. e. a peripheral closed tube of 1/4 wave length.

The sound is conducted to one end of the tube, the other end of which with the help of a rubber tube is connected to the ear of the examiner. The sound at the orifice of the interference tube divides into two parts. The one part continues directly, the other part enters the interference tube and returns with a delay of 1/2 wave length after having been reflected from the obstruction of the interference tube. The two sound waves would completely neutralize each other if the amplitude of the direct sound wave were not slightly greater than that of the reflected one. The person examining thus hears a very weak tone, which becomes considerably stronger, if the interference tube is closed at its opening into the main tube.

Lucae first makes some model tests which are of minor interest now. He then examines fresh ear preparations and the living ear. The interference tube is inserted into the meatus after removal of the peripheral obstruction. The interference tube + the auditory canal should be 1/4 of the wave length of the tone used. The obstruction is formed by the drum.

Both by the preparation tests and on the living ear he finds intensification of the fundamental tone by shutting off the interference tube as a sign that an interference effect has taken place and, thus, a reflection from the ear drum. The damping on account of the interference tube, i. e. the reflection becomes greater, when the tension of the ear drum is increased (pulling

of the tensor tendon at the preparation tests, voluntary tensor contraction, changes of pressure in the middle ear as well as at the preparation tests and on living test subjects).

The comparison between right and left ear on the same person is made with the aid of two interference tubes which are introduced each in its ear and Y-shaped are connected to the main tube. This apparatus is by Lucae called the interference otoscope. Through an alternating closing of the two interference tubes at their openings into the main tube one can compare the damping and thus the reflection from the two sides provided perfect symmetry and airtight connection to the ear.

On examining a number of persons with normal hearing he found in most cases a stronger damping and thus a greater reflection from the right ear. In a minor number of cases a stronger reflection from the left ear or no difference at all.

Lucae then examines some ear diseases from cerumen to labyrinth affections. The examinations have been made and described in detail. Here only the chief results and some details of interest for the following are given.

The meatus. In case of unilateral cerumen a stronger reflection takes place from this ear. Only one single case with unilateral pronounced exostosis has been examined. A *lesser* reflection than from the opposite normal ear was found here.

The middle ear. Ears with tubal catarrh and retraction of the drum showed a very pronounced reflection, far greater than as a result of the contraction of the tensor tympani. The same was found in catarrh of the middle ear. Not unfrequently, however, a smaller reflection was found, i. e. a greater sound absorption on the ear where the hearing was reduced most.

In these cases *Lucae* presumed a secondary labyrinth affection. In case of perforation he often found the reflection greater than from the normal ear, often smaller however. That is explained by the changed resonance conditions. If secretion was found, the reflection was as a rule increased.

The internal ear: Among 200 patients examined, he only finds 5 where he assumes an independent affection of the internal ear. In 4 of these cases there was unilateral or bilateral

hard hearing. There was found less reflection from the deaf or deafest ear. In the fifth case there was a facial paralysis with hypersensibility for the highest and lowest tones on this side. The hearing was otherwise normal. A *greater* reflection was found in the ear homolateral to the facial paralysis.

The limitation of the method lies in its principle, as there only is a possibility of a qualitative or — between right and left ear — comparative examination.

B. IMPEDANCE MEASURING WITH ELECTRO-ACOUSTIC METHODS

West is the first to have done impedance measuring on the ear in 1928. The intention was to find the necessary data for the construction of an artificial ear. Instead of a real ear, the artificial ear should be placed before a telephone. Pressure measurings are made before the telephone and thus examination of its capacity for work (energy radiation) under normal working conditons (i. e., against an impedance which is eqvivalent to that of an ear).

Of the two components of the impedance West is of the opinion that the resistance probably is of the greatest importance for testing the telephones as it plays a rôle in determining the magnitude of the pressure which develops on resonance. The reactance changes the frequency at which resonance takes place.

The resistance is determined with the aid of stationary waves, as described on page 29. A tube was used, the one end of which was connected to "the ear cap" of a telephone and its other end with a source of sound.

The reactance is not measured directly, but is compared with the elastic reactance in a small tube.

The result of the examinations cannot directly be compared with the examinations described in the following, where the Imp. has been measured in the meatus itself. *West* expressly points out that the measurings only refer to the conditions which are present when the ear is held against "the Post Office standard receiver cap", i. e. the Imp. is measured in the opening of the "ear cap".

An extract of the result may, however, be of interest and deserves to be recorded, because, as was mentioned, they were the first impedance measurings on ears.

The resistance was found decreasing with increasing frequency between 370 and 2600 Hz. At 745 Hz. the mean value of measurings on 12 ears was 175 (C. G. S. units) (extreme values 90 and 350).

The reactance was found to be negative at 1100 and 1600 Hz. At 500 Hz. it was in some cases found to be negative, in others positive.

West does not examine more closely where the absorption takes place, but he thinks that a great part of the sound energy is transferred to vibrations of the external ear and the soft parts of the skin. This is substantiated by the great difference in the absorption one finds at small changes in the position of the ear in relation to "the cap". *West* on the contrary does not think that the sound energy which is lost in the external air is considerable, when there is a normal pressure between the ear and "the cap". He demonstrates, however, at the same time that a small leakage may have a considerable influence on the reactance and thus indirectly influence the resistance.

West thus finds that the Imp. varies considerably for external, purely acoustic reasons but supposes that also the mechanical qualities of the ear are of importance. This he bases on the result of examinations of 2 hard hearing ears. In both cases the Imp. was deviating from the normal. The one ear had a particularly high absorption, the other, a particularly low absorption at 1100 Hz. The reactance of the first-named ear was also determined and there was found a mass reactance at a frequency where all normal ears gave an elastic reactance.

Tröger (1930) is the first who determined the Imp. in a tube introduced into the meatus. The tube had an internal diameter of 7 mm. In the ear, on which most of the examinations were made, it could be inserted to a distance of 1.7 cm. from the ear drum. This distance was added to the pipe length in order to get the impedance at the drum itself.

Tröger finds, just as *Geffcken* in 1934, who uses Tröger's

method with a slightly modified technique that the impedance of the ear drum at the lowest frequencies (from 250 Hz.) is chiefly elastic and very great, i. e. the active mass of drum and ossicles is of minor importance at these frequencies. With increasing frequency the elastic component decreases. From about 700 Hz. the Imp. curve plotted in the complex plane has a very tortuous and looped course, sometimes with several loops within each other. In the example of *Geffcken* the curve between 1800 and 1900 Hz. exceeds the real axis.

In *Tröger*'s case the reactance is constantly negative (the examinations have been made up to 3000 Hz.).

The loops run rather differently in the two cases, and also the position of the Imp. at the low frequencies is somewhat different. Below the values for $\bar{w}$ and $\bar{q}$ of *Tröger*'s and *Geffcken*'s cases are recorded with the wave resistance in air as unit for frequencies lying in the neighbourhood of the frequencies used in the following in the writer's own examinations.

Tröger:

Frequency	$\bar{w} \cdot 100$	$-\bar{q} \cdot 100$
355	138	389
450	145	294
570	99	145
758	86	72
800	64	111
1120	281	147
1190	251	36

Geffcken (proximately after the curve):

Frequency	$\bar{w} \cdot 100$	$-\bar{q} \cdot 100$
400	355	550
500	294	465
800	245	294
1100	177	177

At measurings in different ears *Tröger* up to about 600 Hz. finds approximately the same values. Above 600 Hz. greater deviations begin because of resonance phenomena caused by the different elasticity and mass of ear drum and ossicles of different persons.

Keibs in 1936 with his tube method finds the following

values for a test person with normal hearing. The results are calculated to the drum by Keibs.

Keibs:

Frequency	Ear	a %	$-\vartheta^{\circ}$	$\bar{w}\cdot 100$	$-\bar{q}\cdot 100$
290	L.	32	23	199	398
290	R.	33.5	27	158	351
850	L.	46.5	49.5	80	193
850	R.	44	51	71	188

Waetzmann and *Keibs* 1936 reproduce absorption and phase curves and record the values of w, q and u for a normal person. The determinations were made with the tube method.

Waetzmann and *Keibs:*

	Frequency	$\bar{w}\cdot 100$	$-\bar{q}\cdot 100$
Right ear:	300	162	642
	400	113	498
	600	162	279
	800	125	191
	1000	93	162
	1200	105	150
Left ear:	300	181	637
	400	123	490
	600	154	275
	800	113	208
	1000	78	162
	1200	98	137

Waetzmann (1936) and *Kurtz* (1938) have made Imp. measurings with Keib's tube method in connection with determinations of the sensibility of the ear. Both these papers especially treat of the conditions of symmetry (between right and left ear) and hereditary conditions.

The similarity between the Abs. and Phase curves of the right and left ear is emphasized; now and then, however, differences within a smaller or greater range of frequencies occur. The curves plotted for different persons usually are characteristically different, on the other hand there often is a marked similarity between members of the same family.

Waetzmann reports the results for a slightly (perception) deaf son and his still more hard-hearing mother. In spite of

the different hearing there is a marked likeness between the Abs. and phase curves partly between right and left ear, partly between mother and son. Approximately valued after the copied curves the Abs. for the 4 later used frequencies is:

The son: 384 Hz. abt. 10%—512: abt. 30% 768: abt. 60%—1145: abt. 90%
The mother: 384 Hz. abt. 20%—512: abt. 30% 768: abt. 60%—1145: abt.80%

The Phase is at 384 Hz. abt. — 15° and increases steadily to abt. — 70° on the right ear, to abt. — 90° on the left ear, a difference which also is found in the mother.

Kurtz examines 6 members of the same family and demonstrates that the Abs. and phase curves are approximately equal for the mother and two sons on the one side and three daughters on the other side. *Kurtz* also reports the Abs. and phase curves for 2 out of 12 examined normally hearing persons. In the case of one of the persons the Abs. increases steadily from abt. 10% at 150 Hz. to about 80% at 1000 Hz. In the other person the Abs. is at or below 10% up to 400 Hz. With regard to the one ear the Abs. increases from abt. 400 Hz. to slightly above 60% at 1200 Hz. For the other ear the Abs. is low up to abt. 700 Hz., after which it increases to the same value as for the other ear. Thereby there appears a difference in the Abs. of abt. 15% between right and left ear in the mentioned range of frequencies from 400—1200 Hz.

The shape of the phase curves much resembles that of the Abs. curves. There is, however, no difference between right and left ear. In the first mentioned person the phase at 512 Hz. is abt. — 40°, in the last-mentioned, abt. — 10°.

The relation between the impedance and the hearing on experimental change of the Imp. of the ear drum has been examined by *v. Békésy* in 1932 (1). *v. Békésy* examines (with his *chamber* method) the Imp. without and with a water pressure of 10 cm. in the meatus and compares the condition with the subjective change of the intensity of sound. They are found to be of the same range of magnitude because of which the reduced hearing can be explained only by a reduction of the movements of the tympanic membrane and auditory ossicles

(i. e. without necessarily presuming any perception reduction f. i. due to increase of pressure in the labyrinth).

The above reported examinations were, as mentioned, all made with electro-acoustical methods. The reported results will be a little more discussed and compared with the results of own measurings on normal ears in the respective chapter.

C. IMPEDANCE MEASURING WITH THE MEASURING BRIDGE

Results of entirely acoustic ear measurings with the measuring bridge have only been reported by 2 authors, namely, *Waetzmann* in the above mentioned work from 1938 and by *Menzel* in 1940. In both papers only the absorption is determined.

Waetzmann reports the Abs. curves for 3 normally hearing persons, two of whom had great experience as test persons which *Waetzmann* stresses very much. The curves are reproduced on Fig. 6.

1) On one of the persons (Fig. 6 Ktz) series of measurings were carried out in the course of 5 months. The results of the measurings are, for the sake of surveyability, shown on 4 diagrams. The full curves show the Abs. measured with Keibs' tube method about one year earlier. The recorded results are for the greater part mean values of single measurings (with the acoustic bridge). The single measurings seldom deviate by more than a few % from each other. Sometimes the mean value for the one frequency or another fell outside the line of the other measurings — probably on account of bad adjustment of the olive. An example is the value marked with a triangle at the frequency 683 in Fig. 6 (left ear).

2) With regard to the other person (Wtz.) the plain curve also shows the Abs. measured with the tube method about 1 year earlier, the single values are the results obtained with the acoustic bridge. The fairly insignificant difference between the two results *Waetzmann* does not regard as being due to the measuring methods as a similar deviation, but in the opposite direction is found on one ear of the other person.

3) The last mentioned person (K) has only been examined

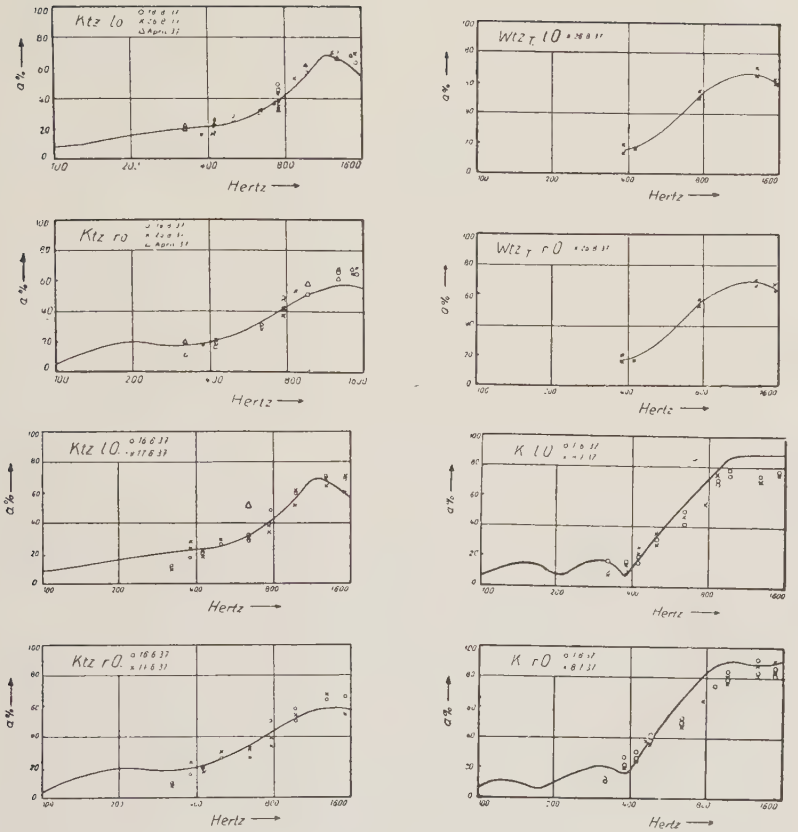


Fig. 6. The Absorption for 3 normally hearing persons.
(After Waetzmann).

with the acoustic bridge. The curves here only connect the single values.

Waetzmann finally emphasizes the similarity between right and left ear. The curves for two of the persons (1 and 2) resemble each other, whereas the curve for No. 3 differs from them. In other persons quite a different shape of the curves was found.

Menzel reproduces Abs. curves (and the corresponding threshold value curves in absolute measure) for 3 persons with normal hearing. As mentioned, he extends the measuring range to about 3500 Hz. The figures themselves are not re-

corded but from the Figure and the text it is evident that the curves have the same form. With increasing frequency an increase of the Abs. appears, which mostly at 2000—2500 Hz. reaches a maximum. Abs. may become 100 %, but reaches in some curves only 70 %. The Abs. is for the 4 frequencies used in the following valued approximately according to the curves:

	Patient 1	Patient 2	Patient 3	
	R. + L. ear	R. + L. ear	R.	L. ear
384	20	20	35	40
512	35	25	40	60
768	55	40	55	70
1145	75	45	70	70

Moreover the Abs. curves and the corresponding threshold values are reproduced for 3 hard-hearing patients.

No. 1. 67 years of age has a very considerable loss of hearing about equal on both ears. Especially on the right ear the hearing decreases still more severely at 2000—6000 Hz. The left ear has a cicatricial drum (due to otitis media). The right ear is reported previously to have been the better one, this now applies to the left ear. The ear drums are not described.

The Abs. measuring shows a great dispersion of the single measurings, which (according to Menzel) often is found in patients with ear diseases. The Abs. curve runs differently for the right and left ear, somewhat lower for the left ear.

(L. ear: 512 Hz. about 25 % — 768 Hz. about 35 % — 1145 Hz. about 60 %). There is thus a fairly high Abs. for both ears.

An otological diagnosis has not been made.

No. 2. 62 years of age. There is a considerable reduction in the hearing for all frequencies, especially above 1500 Hz. the hearing decreases considerably with an increase of the frequency.

The Absorption is high (right and left ear: 384 Hz. about 40 % — 512 Hz. about 70 % — 768 Hz. about 90 % — 1145 Hz. about 90 %).

Diagnosis: Senile deafness (*Menzel*).

No. 3 shows the Abs. of one ear without ear drum. The low Abs. is noticed. The Abs. nevertheless is between 20 and

40 % (except for the highest frequencies where it goes down to about 10 %).

IV. THE TECHNIQUE OF THE EXAMINATION

A. THE CONNECTION OF THE ACOUSTIC BRIDGE TO THE EAR

The difficulties with which former investigators have met when trying to connect the apparatus to the ear are quite evident from their publications.

Waetzmann points out that the qualification for good reproducable measurings is that the olive fits absolutely correctly, which unfortunately is not easy to achieve. The difficulty arises when the rather long, stiff apparatus is to be connected air-tight to the ear.

He recommends a selection of differently shaped olives, the test person chooses the one which suits him best. Usually no head-rest was used, but care was taken to ensure that the person was sitting comfortably beside the apparatus, so that the olive which was screwed to the apparatus could without difficulty be inserted into the meatus. To the first measurings in the clinic he advises only to submit patients who with certainty are able to judge how the olive fits.

Kurtz also mentions that disturbances always occur, which are caused by the test person. These disturbances, he points out, have three causes:

1) Choice of a badly fitting or the bad insertion of a well fitted olive.
2) Impurity! of the ear (cerumen, foreign body!)
3) Unsatisfactory state of health of the test person!

In order to examine the influence of such disturbances tests were performed with well defined sources of error. The measurings showed strongly spreading absorption values; in addition to this an adjustment was only possible for a short time. If the sources of error which were due only to the test person

first were recognised they could as a rule be avoided. The character of the errors, and how they were avoided is not mentioned in detail.

The author's method.

After having made the first introductory examinations, as described above, it was soon found that this method was completely unsuitable for clinical use. It is very difficult to judge how an olive fits, and especially if it fits perfectly air-tight. Likewise it is difficult for the test person to keep the head still, if no support is used. If the patient sits, an ordinary head-rest is not of much use, as the head usually must be kept bent to one side in a rather trying position in order to be able to get the horizontally placed apparatus into the upward directed meatus.

On examination of patients, above all, one should not go by the patient's statement as to whether the olive fits or not, and try to get his head into such a position as to be fairly certain that it is not moved during the measurings.

This can be done by (1) inserting the olive, then (2) taking care that the head is fixed, and finally (3) connecting the apparatus with the olive, and controlling the air-tight connection.

1) THE OLIVE

The tube which is put into the meatus should have the same diameter as the main tube of the acoustic bridge, i. e. 6 mm. A brass tube of 3.4 cm. length with an internal diameter of 6 mm. and an external diameter of 7 mm. was used here. Such a tube is so short that the ear drum may be seen through it, and long enough to manipulate with it without difficulty. That it is just 3.4 cm. is due to the fact that a piece of appropriate tube happened to be of this length. If the tube is chosen slightly shorter or longer naturally makes no difference, but all the tubes should be of exactly the same length.

It was first tried to have a selection of tubes covered with rubber tubes of different thickness, but it was nevertheless often difficult to find one which fitted, especially after having

discovered that it was not sufficient that it fitted air-tight into the most external part of the cartilaginous meatus, but it had to be introduced just to the oval bony wall of the meatus. We therefore proceeded to fit them to each separate ear.

Around one end of the tube is placed a layer of Stent's mass, or rather Kerr's impression compound so that a suitable piece of the other end of the tube is free. When heated in water the compound becomes plastic, and remains so on cooling off to a temperature permitting of introducing it into the meatus. This is done during a simultaneous otoscopy so that the position of the tube is controlled with the eye, and care being taken it is inserted as far as possible, — i. e. to the bony meatus where the high sensibility begins — and at the same time is directed towards the ear drum or at any rate towards the free lumen of the auditory canal. If otoscopy is not performed, the tube will often be put against the ear wall and partly closed by it.

The compound can be pushed with a spatula towards the meatus and the innermost part of the cavum conchae. After this the tube is removed, cooled, greased with vaseline and put in again. The position is controlled by otoscopy. The outer end of the tube usually points more or less downwards.

This sounds, perhaps, a little awkward, but when reduced to a system, it does not take more time than trying a number of different olives.

(For the tube adjusted to the ear the expression "olive" is used, even though it is not quite adequate).

2) FIXATION OF THE HEAD

Virtually all the examinations described in this work have been made on patients in recumbent dorsal posture. During the very first examinations the head was supported by sand bags, later a bronchoscopy head-rest was used — on a ball-and-socket-joint — and found very suitable for this purpose. The head-rest was attached to an ordinary couch, the head being turned and bent so that the tube from the ear was horizontal in a suitable position, which means chiefly that the

shoulder did not interfere when the apparatus was connected to the ear. It is important that the patient's body as well as his head rest comfortably. The head was not fixed ulteriorly with straps or the like.

3) THE CONNECTION OF THE ACOUSTIC BRIDGE WITH THE OLIVE

The main tube of the acoustic bridge was adjusted in such a way that it was an exact extension of the tube from the ear, and was then connected with it.

The air-tight connection was achieved in the following manner: A rubber tube of 3—4 cm. length was placed beforehand on the main tube of the apparatus, just a little from the end. When contact with the tube from the ear was achieved the rubber tube was pushed on to this tube. When the diameter of the rubber tube only is slightly smaller than that of the tube, closure will be complete. It may easily slide, if talcum is used. Nevertheless, it is difficult to avoid manipulating with the olive and thus change its position.

Therefore a piece of rubber tubing was used which just fitted the tube and, owing to the use of talcum, could easily glide over it. In order, in this case, to get an air-tight connection, it was necessary to use a circular pressure on the rubber tube corresponding to the connection of the two tubes. This was achieved by means of a small clip consisting of a thin brass band about 2 cm. wide, which was bent round the tube; the narrow end of the band was pushed through a transverse slit in the wider end. A spring connected with the two ends tightened the metal band round the rubber tube.

In both ways an air-tight connection is easily obtained. The latter method has the advantage that it is easier to push the rubber tube over the tube of the olive without running the risk of changing the position of the olive.

Finally the air-tight connection was controlled. It was done with the aid of a small manometer placed on a side-tube of a tube which connected the Y-tube of the auscultation tubes with the auscultation place of the acoustic bridge. By making

a bend on the rubber tube from the Y-tube and compressing it an overpressure of about 15 cm. H_2O is easily achieved. Before that the felt tube and piston of the comparison resistance have been pushed completely to the bottom. They can be made to close up completely, if rubber discs are placed on the two drags.

B. THE MEASURING METHOD

After having achieved and controlled the air-tight connection between the acoustic bridge and meatus the frequency is gauged.

The frequency graduations of the generators used could only be utilized for an approximate adjustment. The exact adjustment, as was mentioned, was always done with the aid of tuning-forks, and the use of the "Beats". With 512 and 768 Hz., where excellent tuning-forks were at disposal an accurate adjustment could always be obtained. For 384 and 1145 Hz. weighted tuning-forks with higher frequency were used. They had a relatively small initial intensity and a short vibration time.

If there was a little noise in the room, the adjustment was difficult. Therefore a slightly greater inaccuracy in the adjustment of the frequency at these two frequencies must be reckoned with. During the tuning the current from the generator was switched on to a small loud-speaker. It was — in order not to tire the ear unnecessarily — switched on to the telephone of the acoustic bridge just before each measuring. As there was a constant sliding of the zero on the generators used, the frequency was controlled before each measuring.

The examination itself was usually begun with 512 Hz., then 768, 384 and 1145 Hz. in the mentioned succession.

Subsequently either the apparatus + the olive were removed or the apparatus was separated from the olive, which remained in the meatus. The olive was fixed anew or its position was corrected (otoscopy) and the apparatus was connected afresh; in this way the measurings were usually made 3 times in all. The mean number of the three measurings at each frequency were used.

After the last measuring the muscle reflex has been examined, which will be described later.

Finally, in some cases the Imp. change was examined by Toynbee's test and after Politzer's air douche. Whether a change is caused by an ordinary deglutition will as a rule have been observed earlier during the Imp. measuring. The same succession was applied in examining the opposite ear.

C. STATISTICS EMPLOYED

For the estimation of the measurings and the material were employed:

The mean value $\overline{X} = \frac{\Sigma X}{n}$; where X is the single examination.

n is the number of observations.

The dispersion (the mean error of the single examination, the standard deviation).

$$s = \sqrt{\frac{\Sigma (X - \overline{X})^2}{n - 1}};$$

The area within $\overline{X} \pm s$ includes at sufficiently great materials about 67 %, and within $\overline{X} \pm 2s$ about 95 % of the observations.

The mean error on the mean number $e = \frac{s}{\sqrt{n}}$;

For comparison of the two mean values $\overline{X}$ and $\overline{Y}$ was in some cases used the magnitude:

$$t = \frac{\overline{X} - \overline{Y}}{e_D}$$

where $e_D = \sqrt{\frac{s^2}{n_1} - \frac{s^2}{n_2}}$ is the mean error of $\overline{X} - \overline{Y}$;

$$s = \sqrt{\frac{\Sigma (X - \overline{X})^2 + \Sigma (Y - \overline{Y})^2}{n_1 + n_2 - 2}};$$

n_1 and n_2 are the number in the two series of observations.

For the valuation of t is used the calculated t-value (i. e. the value found in the Table), which corresponds to the 1 % level. If the t value found in the measurings is greater than that found in the Tables it is warrantable to presume that the difference $\overline{X} - \overline{Y}$ is an expression of a reality, if they are equal, there is only 1 % probability that the two distributions are equal. (after *Kemp*).

V. SOURCES OF ERROR IN EAR MEASURINGS

As sources of error may be regarded all changes and differences of the measured Imp. which are not caused by mechanical conditions in the vibrating part of the sound-conducting apparatus itself.

Even if the causes mostly are the same, it is necessary to examine firstly:

1) Possible causes of the change of Imp. at measurings on the same ear. Next:

2) The differences of Imp. which may be expected to be added hereto at measurings on different ears, right and left ear on the same person or on ears of different persons.

The measuring errors arise partly at the connection of the apparatus to the ear, partly — dependent or independent of this — as a consequence of differences of Imp. in that part of the meatus which is situated between the "*measuring plane*" and the ear drum, finally the possibility of sources of error in and medially to the drum must be reckoned with.

A. MEASURING ERRORS ON ACCOUNT OF CONNECTION OF THE APPARATUS TO THE EAR

Only because of the connection to the ear there is already the possibility of very considerable measuring errors — namely, if there are leakages in the connection. Even small leakages will compromise the results entirely.

With the model arrangement described below (p. 76) an experiment was performed in which corresponding to the place of the meatus a hole with an initial diameter of 0.5 mm. was bored in the tube; after each measuring with the employed 4 frequencies that diameter was enlarged at the beginning with 0.1 mm., later with 1 mm. until 5 mm.

The Abs. immediately increases considerably and the Imp. in the complex plane moves in a spiral-shaped curve with initially increasing values of w and decreasing value of q towards the real axis. After having passed this the Imp. approaches, with decreasing value of w and initially increasing, subsequently decreasing, value of q the zero point of coordinates. The Abs. after having reached a maximum decreases thus again and finally becomes very small.

This experiment in connection with experiments of ear measuring shows sufficiently clearly that it is necessary to make sure of a perfectly air-tight connection of the apparatus to the ear, as an absolute prerequisite of applicable measuring results.

A possible source of error may here be mentioned, which was mentioned by *v. Békésy* (1932) and *Dishoeck* (1940) in another connection.

Both the mentioned authors are of opinion that, by too vigorous introduction of a tube into the meatus, the skin of the meatus may be displaced and thus transfer a pressure to the ear drum. None of them gives any reason for this presumption which must beforehand appear improbable.

In experiments on three fresh ear preperations it has not been possible to demonstrate any change of the Imp. when heavy pressure was applied to the olive which beforehand as far as possible had been inserted into the auditory canal.

The experiments were made partly with an ordinary slightly rough — not greased — olive, partly with an olive where the tube had been pushed through so that its fairly sharp edge itself was able to displace the skin. After the adjustment of the comparison resistance the preparation was alternately pressed firmly against the acoustic bridge and detached again.

Thereby a small change of the Phase was caused but in none of the cases, a change of the Abs.

Nor was there found any change of Abs. on the living ear after alternating pressure against a deeply inserted olive.

If one should find the same as *v. Békésy* and *Dishoeck*, namely a decrease of the Abs. produced by pressure against a deeply inserted olive, that might possibly and more probably be explained by an increase of the tension of the ear drum due to contraction of the tensor tympani in response to vagus irritation.

It is a different thing that, in measuring on the living ear, often with deep insertion of the olive — with or without pressure — one obtains a lower Abs. than if it is placed far outward in the meatus. But to express this another way: to obtain this higher Abs., if the olive is placed far out, it must be placed *far out* in the cartilaginous meatus. The explanation of this difference in the Abs. by a pressure against the drum due to a displacement of the skin of the cartilaginous meatus is rather far-fetched, particularly as the skin at the transition to the bony meatus, adheres rather firmly to the underlayer. A more probable explanation of this condition will be set forth in a subsequent section: changes of the Imp. due to Abs. in the wall of the auditory canal.

B. THE IMPORTANCE OF THE INLET IMPEDANCE IN THE SECTION OF THE MEATUS WHICH LIES BETWEEN THE OPENING OF THE TUBE (MEASURING PLANE) AND THE TYMPANIC MEMBRANE

1) CHANGES OF THE IMP. ON VARIATIONS OF THE LENGTH AND TRANSVERSE AREA OF THE MEATUS

The section of the meatus between the opening of the tube and the ear drum has in different ears a different length and transverse area. In repeated measurings on the same ear, the length will be able to vary according to how deep the olive

is inserted. The transverse area will be able to vary in response to different degrees of compression of the meatus or if the olive is displaced so that the orifice of the tube is partly closed by the wall of the meatus. At measurings on different ears as well as at repeated measurings on the same ear there will therefore be a possibility of differences and changes of the measured Impedance.

In order to get an idea of how the two components of the impedance are changed and how great the changes are which should be reckoned with, there were performed partly some model experiments, partly a few preparation experiments and finally, measuring on the living ear.

For the model experiments a variable Imp. constructed entirely as the "*comparison resistance*" of the acoustic bridge was used as "artificial ear". At a certain frequency felt tube and piston can be adjusted to a definite Imp. which can be found by measurement of an ear. This is done in order to be able to carry out the model experiments with values of a and ϑ of the same order of magnitude as at the ear measurings. At this frequency the "artificial ear" must correspond to an ear with regard to the sound reflection, and this is the only thing of interest at the measurings. What happens to the sound energy after having passed the felt plate is of no importance in this connection. An "artificial ear" constructed in this way cannot (but perhaps exceptionally) by the same adjustment of felt and piston be brought to resemble an ear for all the frequencies used.

Changes of the distance from measuring plane to the ear drum.

Such a change will be expected to give a pure change of Phase after the formula p. 34. The model experiments prove to agree herewith. The ear model is put into direct prolongation of the main tube of the acoustic bridge with the aid of a thick-walled rubber tube the diameter of which corresponds to the diameter of the main tube. The felt tube and piston of the model are adjusted so that Abs. and Phase in the measuring plane are f. i. 30 % and 29° for 512 Hz. (Values are to be found on measuring of a normal ear). The ear model is moved

outwards and a measuring is made for each mm. to a distance of 10 mm. As is seen from the figures (Table 1) the Phase increases numerically with the distance, the Abs. persists perfectly constant. Nor has the Abs. been influenced in any particular degree by the short piece of rubber tube, the damping of which (β) differs from that of the brass pipe.

On calculation it is found that the increase of the distance between measuring plane and Imp. of 1 cm. for the employed frequencies 384, 512, 768 and 1145 Hz. means an increase of ϑ of 8, 11, 16 and 24°, respectively. The Abs. will in the same piece of tube for 384 and 1145 Hz. respectively be 0.9% and 1.5%, i. e. of no importance.

Table 1. Model experiment showing the change of Phase by the change of the distance between an Impedance and the acoustic bridge. The Absorption remained constant. 512 Hz.

The distance in mm.	a %	$-\vartheta^0$ (measured)	$-\vartheta^0$ (calculated)
10	30	42	40
9	—	40	
8	—	39	
7	—	38	
6	—	37	
5	—	35	34
4	—	34	
3	—	33	
2	—	32	
1	—	31	
0	—	29	

In ear measurings — when measuring the same ear — the possible difference of distance will be dependent on the length and width of the meatus. According to *Cunningham* the length of the cartilaginous meatus is 8 mm. Presumably a difference of about 6—8 mm. in the position of the olive is maximum. If care is taken every time to introduce the well fitted olive as far as possible into the meatus, the variations in the distance will decrease. By repeated measurings on the same ear (p. 94) a mean dispersion of 1.6° is found for 512 Hz., i. e. 95% of the measurings are within an area of about 6°. That corresponds exactly to the presumed difference of distance.

In order to get an idea of what differences in the distance between measuring plane and ear drum may be reckoned with on ears of different persons, some measurings of this distance have been made.

A smooth tube with an external diameter of 7 mm. was inserted as far as possible into the auditory canal, in some very wide auditory canals as far as possible without inconvenience to the patient, i. e. to the bony wall of the auditory canal.

The distance was measured from the innermost part of the tube to the umbo. It is thus no anatomically defined part of the meatus which has been measured, but a length which is determined by the length and especially the width of the meatus.

Measurings were made on 50 men and women from 20 to 64 years of age with normal ears.

The smallest distance was 9 mm., the greatest 23 mm. In most ears the distance was 14—18 mm.

Alone on account of a difference in the distance from tube to ear drum due to differences of the anatomy of the ear, there can thus be a difference of Phase of 11, 15, 23 and 34° for 384, 512, 768 and 1145 Hz. respectively.

The difference in the measured distance on right and left ear of the 50 persons was maximally 5 mm., mostly 0—3 mm. This should give a phase difference of about 5° at the utmost.

Changes in the lumen of the meatus.

Physically a change of the lumen of the meatus means that between the tube of the olive with 6 mm. internal diameter and the Imp. there are inserted pieces of tubes of different length with another diameter.

In order to get an idea of what importance the differences in the diameter of the meatus are, some model experiments were made with the previously described Imp. which, with a brass tube of 1.3 cm. length as mediate link, was brought into connection with the acoustic bridge.

The brass tube functions as meatus model, 1.3 cm. is the length of the bony auditory canal on an incidental preparation with apparently ordinary dimensions of the canal used in these measurings.

This length is somewhat below the average length of the bony meatus, which by *Cunningham* has been stated to be 1.6 cm.

In Table 2 are recorded the values for a and ϑ when the diameter of the 1.3 cm. long tube is reduced from 8 to 3 mm. For 512 and 768 Hz. the values of $\bar{w}$, $\bar{q}$ and u are quoted too.

Table 2. Model experiment showing the change of impedance at changes of the diameter of a piece of tube inserted between acoustic bridge and impedance.

$n = 512$ Internal diameter in mm.	a %	$-\vartheta°$	$\bar{w}\cdot 100$	$-\bar{q}\cdot 100$	$u\cdot 100$
8	26	44	52	239	8.7
7	29	38	76	272	9.5
6	29	34	94	303	9 3
5	30	31	113	325	9.5
4	30	27	144	364	9.4
3	36	27	168	340	11.7

$n = 768$ Internal diameter in mm.	a %	$-\vartheta°$	$\bar{w}\cdot 100$	$-\bar{q}\cdot 100$	$u\cdot 100$
8	32	68	30	145	13.6
7	39	61	46	161	16.4
6	41	56	56	175	16.5
5	41	52	64	189	16.1
4	43	50	72	193	16.9
3	59	52	95	163	26.6

Internal diameter in mm.	$n = 384$		$n = 1145$	
	a %	$-\vartheta°$	a %	$-\vartheta°$
8	18	39	24	84
7	20	35	24	80
6	19	31	31	71
5	20	29	36	72

The auditory canal itself (from the preparation) was then inserted instead of the brass tube. The following values of a and ϑ have been arrived at:

	384	512	768	1145
a %	19	29	37	27
$-\vartheta°$	37	41	64	79

It is seen that this auditory canal corresponds to a brass tube of the same length as a meatus with a diameter between 7 and 8 mm. (Only at 1145 Hz. is there a minor deviation for some uncertain reason). Measurings of the dimensions of the ear apart from the length are difficult to make because of the irregular and varying transverse area.

In addition to these experiments on the changes in the diameter of the whole bony meatus, it is of interest to examine how localised constrictions of the lumen work.

In measuring the same ear a compression of the meatus is of this character. In different ears exostoses may f. i. be thought to give different results of the measuring.

The same experimental arrangement was used to examine this. The tube which represents the meatus had an internal diameter of 6 mm. At the end which turned towards the acoustic bridge a 5 mm. thick plate of Stent's mass was applied and through heat fixed along the tube. In this plate a hole was bored which was enlarged after each measuring (from 1.5 to 6 mm.).

The results of the measurings are shown in Table 3.

Table 3.

Diameter of the hole in mm.		1.5	2.0	3.0	4.0	5.0	6.0
$n = 512$	a %	53	37	33	30	29	28
	$-\vartheta^0$	34	32	32	32	32	33
$n = 768$	a %	86	62	53	43	41	35
	$-\vartheta^0$	100	71	66	59	55	54

For the sake of comparison a rounded off exostosis-like prominence was placed in the preparation of the ear canal. There only remained so narrow a crescent-shaped slit that insight into the depth was quite impossible.

It corresponds thus to an exostosis which was more pronounced than is usually seen.

The changes in a and ϑ were for 512 and 768 Hz.: (cf. the values for the auditory canal preparation itself).

512 Hz. $a = 35\,\%$, $-\vartheta = 34°$; 768 Hz. $a = 45\,\%$, $-\vartheta = 59°$.

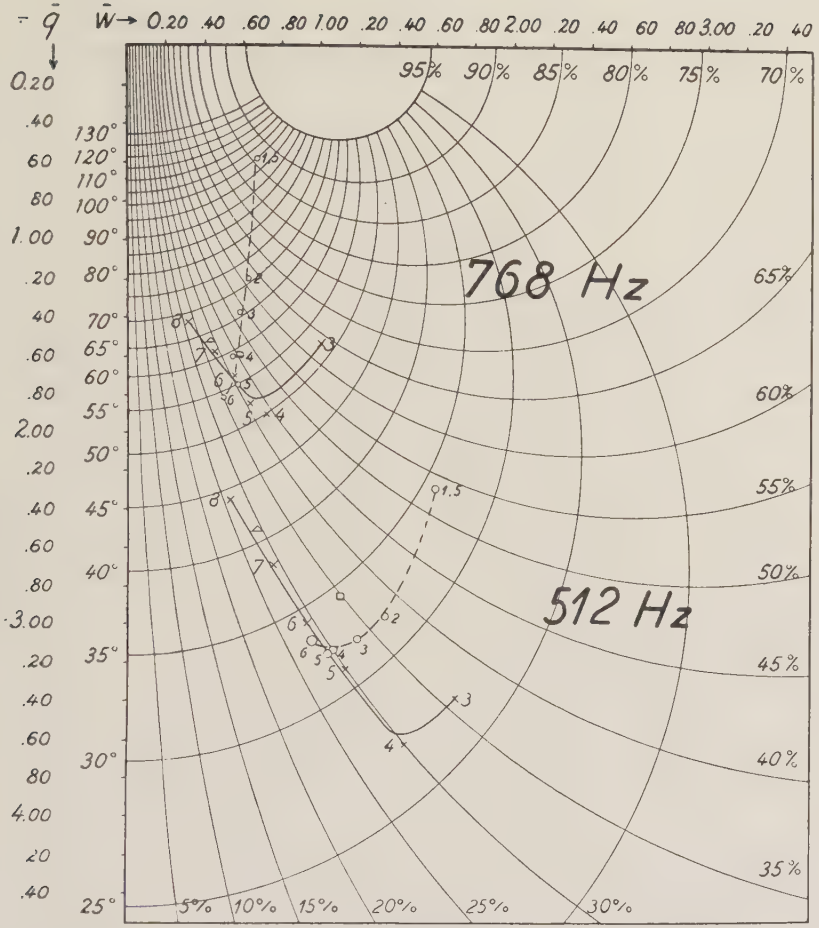


Fig. 7. Model experiment showing the change of Absorption and Phase by insertion of a tube with a different diameter between acoustic bridge and an Impedance (an "artificial ear").

The fully drawn curves connect the impedance values corresponding to the figures in Table 2, i. e. the changes of the diameter of the whole tube.

The dotted curves correspond to the figures in Table 3, i. e. to the localized narrowing of lumen. △ represents the impedance with the ear canal preparation instead of the brass tube.

□ "Exostosis" in the ear canal.

The figures give the internal diameter of the tubes in mm.

To illustrate the results of these model and preparation experiments, those obtained for 512 and 768 Hz. are recorded in the diagram Fig. 7.

It is seen that, for 512 Hz. (and the same applies to 384 Hz.), a change of the diameter of the whole inserted part of the tube almost solely gives a change of the phase. An enlargement of the diameter gives a numerically greater phase difference whereas a reduction gives a smaller difference of phase between the reflected and the incident sound wave. Only when the diameter becomes as small as about 3 mm. is there also a change of Abs. For 768 Hz. (and 1145 Hz.) a change of the diameter gives a change of the Phase as well as — in a smaller degree — of the Abs. When the diameter is reduced from 8 to 4 mm., the Phase is reduced about 18°, the Abs. increasing about 11 %. When the diameter is further reduced, a great increase of the Abs. ensues.

The localized narrowings of lumen only give small changes until the small diameters are reached. Then there ensues a great increase of Abs. at the higher frequencies, smaller at the lower frequencies.

Patients and normal persons submitted to acoustic measuring will fairly seldom be found to have such narrow auditory canals as correspond to the transverse area of a tube with a diameter of 3—4 mm. Patients, i. e. persons with reduction of hearing, whom it is of interest to examine with Imp. measuring, in fact do not differ from ordinary persons with regard to the dimensions of the auditory canal. The small changes which, in otosclerosis, may be caused by atrophy of the auditory canal, certainly are of no importance.

Even if the auditory canal is narrow or constricted, f. i. by exostoses, the lumen will as a rule be crescent-shaped or irregular so that the transverse area nevertheless is comparatively large.

The most frequent cause of the most pronounced stenoses: inflammations will in themselves contra-indicate the introduction of an olive.

Conclusion: On account of the normal variations of the length and width of the meatus there should — to judge from

the model experiments — mainly ensue changes of the measured Phase and only in a small degree of the Abs. The same should be the case by repeated measurements on the same ear on account of variations in the position of the olive, if care is taken to prevent marked degrees of compression of the meatus.

The results arrived at are in conformity with theoretical reflections on the importance of the insertion of a piece of tube with one or another diameter into a system of tubes.

To simplify the conditions it is presumed that there is no reflection from the end of the tube and that there is no sound Abs. of the walls of the tube, i. e. an infinite tube without damping. For the transport of energy and the phase difference in such a system of tubes the following formulae are applicable:

$$P_r = \frac{1}{1 + \frac{(m^2 - 1)^2}{4\,m^2} \cdot \sin^2 k \cdot L}; \quad tg\,\Theta = \frac{m^2 + 1}{2\,m} \cdot tg\,k \cdot L.$$

where P_r = the ratio between the transmitted amount of energy and the incident energy.

Θ = the difference of phase between the incident and the transmitted wave.

$m = \frac{s_2}{s_1}$, where s_1 = the transverse area of the main tube.

s_2 = the transverse area of the inserted piece of tube.

$k \cdot L = \frac{2\,\pi\,L}{\lambda}$; where L = the length of the inserted piece of tube.

(The formulae are derived from the formulae given in *Stewart* and *Lindsay:* Acoustics, London 1931, p. 77, with the simplification due to the fact that the tube has the same diameter on both sides of the inserted piece of tube).

With the above used value of L (1.3 cm.) and the used frequencies, where the wave length is 29.7 cm. for the highest: 1145 Hz., $k \cdot L$ will be about 16°; $\sin^2 k \cdot L = 0{,}07$.

$\frac{(m^2 - 1)}{4\,m}$ f. i. for an inserted piece of tube with a diameter of 0.4 cm. becomes 1,1. $P_r = 0.93$. With 512 Hz. and the same diameter of tube $P_r = 0.98$, i. e. at any rate very small changes for the lower frequencies.

The phase difference will be of greater importance, as is evident from the formula ($tg\,k\,L$). A calculation according to the formula does not give the same result as the model experiments. The calculation gives a change of phase in the same direction whether the diameter of the tube be made larger or smaller than the diameter of the main tube. The difference may

be due to the fact that in the formula the reflected sound wave has not being taken into account. A closer study of this matter has not been made, as the author assumes to have gained sufficient information for practical use from the model experiments and to have shown that they are in accordance with the theory in regard to the main point: A change of the diameter of an inserted piece of tube gives a change of Phase, but only a small change of the traversing quantity of the energy.

2. CHANGES OF THE IMPEDANCE ON ACCOUNT OF ABSORPTION IN THE WALL OF THE AUDITORY CANAL

Proceeding to the measurements of the ears a single example of measurements on the same ear will be sufficient to prove that the results are *not* as expected.

An ear (No. 26 left ear) with chronic suppuration was chosen where one would expect a low absorption and where there is no reason to expect variations in the Imp. caused in or mesially to the drum. At repeated measurements on this ear with olives of different size highly spreading Abs. values have been found.

The olives were partly so big that they fitted the most external part of the very wide meatus, partly so small that it was possible to get them in quite close to the bony meatus, i. e. as far as they could be put without inconvenience to the patient.

In these measurements the olive was not — as in the model experiments — gradually displaced outwards mm. after mm. The auditory canal usually has a narrow part at the beginning of pars ossea, and then extends (which was especially pronounced in this meatus) sometimes becoming a little narrower again at the meatus acousticus externus. If an olive fitted to the innermost part of the meatus is placed outward, it soon reaches those parts of the meatus where the diameter is bigger than the olive. It may then let the air through; but this can be prevented. It will on the other hand be very difficult — when an increase of Abs. is found — to deny that the sound in one way or other can escape or be absorbed between olive and canal. This does not seem to be the case, as later experiments show, but for this reason olives of different sizes

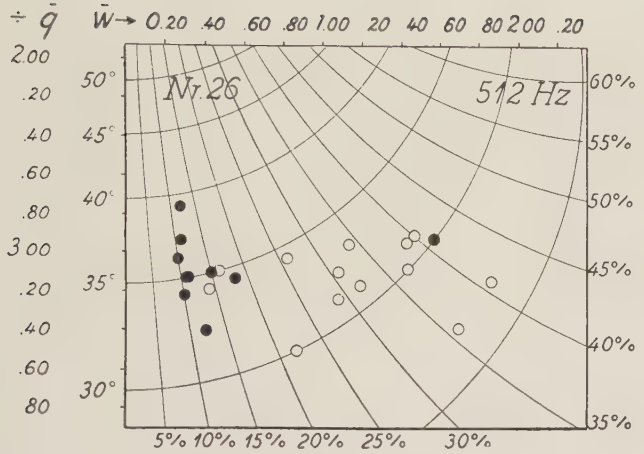


Fig. 8.

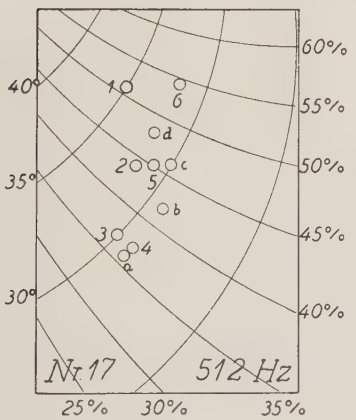


Fig. 9 a.

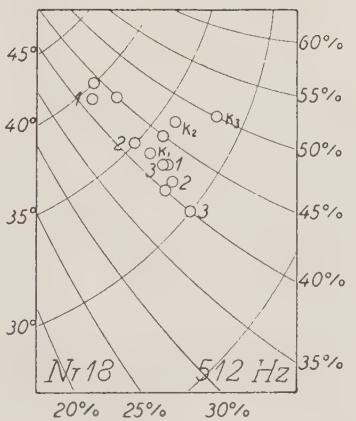


Fig. 9 b.

Figs. 8 and 9. Change of impedance on insertion of the olive deep into and farther out in the meatus. To fig. 8. ● = small olive — ○ = big olive.

fitted to the meatus deep inwards and further outwards were used at these measurings.

The measurements were repeated many times in the course of 5 days.

Fig. 8 shows the Imp. values. The measured Abs.s lie between 10 % and 40 %, the Phase between 27 ° and 39 °. The measurements with the smallest olives collectively lie at

about 10—15 %. The other measurements are spread between 15 % and 40 %. The two measurements with a big olive and low Abs. were obtained by pressing the olive firmly into the meatus. This was made possible in this very wide meatus without causing compression and without the tube being pressed against the walls of the meatus — because it too was very straight. The single measuring result with a small olive and high Abs., may be caused f. i. by a movement of the patient's head having caused the olive to slip farther outward in the ear canal.

A series of measurements on this ear thus show that, in using olives of different sizes, much higher and more varied Abs. values are obtained when they are fitted to the outermost part of the meatus than if they are fitted to the innermost part.

The Phase has changed relatively little and in the opposite direction of what would be expected.

In similar experiments on other ears the same change of Abs. was found, and also change of the Phase in the direction one would expect, namely, an increase of the difference of phase with increase of the distance to the drum. An example of this is No. 17 left ear. It is a normal ear with wide meatus. Fig. 9 a shows the measurements.

There was inserted partly a small olive (*a*) (fitted to the innermost part of the meatus) which then was pulled more and more outward (*b*, *c*, *d*.), partly a bigger olive (1) (fitted to the outermost part of the meatus) which first was introduced inwards (2, 3, 4) and then outwards again (5, 6). The Abs. thereby varies from 36 % (*a*) to 54 % (6), the Phase from 29 ° (*a*) to 32 ° (6). Thus also here is a fairly great increase of the Abs. and only a minor change of the Phase, when the olive is placed farther outward in the meatus.

Several similar examinations show exactly the same.

In measuring on other ears on the contrary only a slight change of Abs. was found and then always a change of the Phase as expected.

An example of this is No. 18, left ear. It is a normal ear with a long and rather narrow meatus (Fig. 9b). The Olive was here placed far out in the meatus (1). It was then pushed

farther and farther in (2, 3). K_1, K_2, K_3 are 3 measurings, where the olive was loosened gradually, after complete compression of the meatus. (Compensation impossible, no minimum) 00 shows the other measurings made the same day.

Abs. lies here between 40 % and 45 %, the Phase between 30° and 40° (the values where there was a compression not included).

According to the mentioned examples in connection with several other measurings performed especially for this reason, and experience gained by the clinical use of the Impedance measuring, it is sure that the Abs. values often are higher when the olive is far out in the meatus than when it is farther inside.

If leakings are excluded, as is justified after the precautions taken, the only possible explanation seems to be that a part of the sound energy escapes through or is absorbed in the cartilaginous wall of the meatus.

Studies reported by *v. Békésy* and *Geffcken* go against this assumption.

V. Békésy (2) (1932) after observation in the ear-microscope is of the opinion that the walls of the meatus must be considered stiff in relation to the mobility of the drum, as an excessive hydrostatic pressure of 20 cm. only results in a displacement of the drum. *Geffcken* at an impedance measuring on an ear, where the drum owing to otitus media was completely adherent (verwachsen), has shown that this ear reacted completely as a stiff, hard-closed canal. *Geffcken* thinks that this is an experimental proof of the assumption theoretically substantiated by *v. Békésy* that the meatus must be considered to be acoustically stiff.

The examinations made by both these authors were only made on single ears, nor do they mention anything about the size of the meatus in relation to the inserted tube, i. e. how deep into the meatus it has been pushed. As these examinations were made especially with a view to study the conditions of the meatus it may be presumed that the measurings also were made with the tube in the outermost part of the meatus, but even in that case it has only been shown that

no sound Abs. in the meatus has taken place in these single cases.

Many examinations of the present material show the same, i. e. the same Abs. with the olive deep insisde and farther outward in the meatus, but in other cases the described high Abs. is found with the olive in the outermost part of the meatus.

This difference must probably be attributed to the different anatomic conditions: the width of the cartilaginous meatus in proportion to the inserted olive (tube), its length and curvature and, possibly, differences of elasticity of the tissues.

The source of error thus arising is of great importance, and if disregarded, it may become the cause of getting quite erroneous values. In nearly all ears it is possible to insert an olive — produced as described — close to the bony meatus, as the diameter of the meatus at the beginning of pars cartiliginea according to *Bezold* lies between 9.08 mm. and 6.54 mm.

By thus introducing the "measuring plane" up to the innermost part of the cartilaginous meatus the part lying outside of it was beforehand excluded from exerting any influence on the result.

In some auditory canals it is not possible to insert a tube with an outer diameter of 7 mm. into the meatus, or only for a rather short distance. Only to very low Abs. values may in such cases be attached real importance. It will certainly be possible in those cases to use an olive made from a tube with a smaller diameter, but it is then necessary to find a correction for each of the used frequencies. In order not to go away from the theory of the acoustic bridge itself by introducing a smaller tube and thus change the lumen of the main tube, persons with very narrow canals have hitherto been avoided. A possibility of obtaining an idea of whether the Abs. measured in a narrow meatus is correct is afforded by using an olive with a smaller tube. As it mainly is a change of Phase, which has to be corrected, it may be reckoned with, if there is no greater difference between the Abs. measured with the ordinary olive far outward in the meatus and a smaller farther in, that it probably is correct, i. e. determined by the drum.

3. CHANGES OF THE IMPEDANCE ON ACCOUNT OF CHANGES OF TEMPERATURE

The temperature in the tube of the acoustic bridge may be changed in the first place by a change of the room temperature: in the second place by warmth from the ear being imparted to the abutting air column. The influence of the temperature on Phase and Abs. was discussed previously. Only the change of the Phase can be thought to be of importance, but as is evident from the calculated examples in chapter II, page 46, the changes will be so small in comparison to the changes of Phase to be reckoned with owing to the reasons discussed in this chapter that they may be disregarded.

C. SOURCES OF ERROR IN AND MEDIALLY TO THE TYMPANIC MEMBRANE

Possible sources of error in the tympanic membrane are discussed in the introduction of the clinical part.

The only source of error medially to the tympanic membrane which has been acknowledged, is an open tube, as it is described on page 105, but it is possible — and probable — that also other factors in the middle ear and its surroundings (besides the sound conducting apparatus) may influence the Imp. measured in the meatus.

It may be thought that the cells in the mastoid process must absorb a certain amount of sound energy, dependent on their development and access to them through aditus ad antrum. The same may perhaps be thought to be the case with greater dehiscences in the walls of the tympanic cavity.

These conditions have not been examined, but are mentioned, as it is possible that they are of importance.

Recapitulation: This chapter treats of the possible sources of error to be reckoned with in ear measurings. By model, preparation and ear experiments it was examined to what changes and to how great changes every individual isolated source of error may be anticipated to give rise.

Leakage at the connection of the apparatus to the meatus will give quite misleading results. Errors of this origin will generally

be easily recognized, whether the Imp. is found to be of quite another kind and magnitude than usually in ear measurings or because the dispersion of the several measurings is unusually great. Air-tight connection between apparatus and auditory canal is the first and chief condition for the obtainment of serviceable results.

The importance of the inlet impedance in the part of the auditory canal lying between tube opening (measuring plane) and tympanic membrane.

Difference of distance between the olive (measuring plane) and the tympanic membrane. By measurings on the same ear the maximal difference in the seat of the olive is estimated to amount to from 6 to 8 mm.; at 512 Hz. that corresponds to a phase difference of 6—7°, at 768 Hz. to about 10°. By measurings on different ears there is an additional difference in the length of the auditory canal, which maximally amounts to about 14 mm. Adding to this the afore-named 6 mm., the maximal difference of distance becomes about 20 mm. That corresponds to about 22° at 512 Hz., to 33° at 768 Hz. Mostly the difference is less than about 5 mm., particularly on the ears here selected.

At measurings on right and left ear of the same person the difference mostly is 0—3 mm., i. e. a difference of $< 3°$ (512 Hz.) and $< 5°$ (768 Hz.).

Changes and differences of lumen of the auditory canal. By model experiments it was examined what changes may be anticipated. By measurings on the same ear changes of lumen arise, if the olive is displaced and partially obstructed by the wall of the canal or if the cartilaginous auditory canal is compressed. On different ears there will in addition arise anatomical differences (eventually exostoses).

Change of lumen will to begin with chiefly give rise to change of Phase, which thus becomes numerically smaller when the diameter is reduced, whereas it becomes greater when the diameter increases. Not before the lumen decreases considerably (corresponding to a tube measuring about 3 mm. in diameter) does a change of Abs. in the direction of greater Abs. occur. Partial compression of the auditory canal or partial occlusion of the tube of the olive by the wall of the meatus

will thus usually give rise to greater Abs. In case of complete obstruction the Abs. naturally becomes nought or abortive.

Change of Imp. on account of Abs. in the cartilaginous meatus. By placing the olive far outward in the cartilaginous auditory canal too high values of Abs. may be obtained, probably because part of the sound is absorbed in the wall of the canal. Therefore it is necessary to insert the olive quite up to the bony ear canal.

Errors on account of change of temperature in the system of tubes are regarded as being of no practical importance in ear measurings.

A couple of *possible sources of error medial to the drum* are mentioned without, however, being examined more closely.

These different sources of error may be thought to concur or to counteract each other, whence it is very difficult to estimate what changes may be anticipated. Only estimation of the dispersion in serial measurings and measurings on different ears will afford a clue as to the magnitude of the variations which must be reckoned with in practice.

VI. IMPEDANCE MEASURING ON NORMAL EARS

The examinations on normal ears were made according to the following scheme:

A. Measurings on the same ear.

1. Repeated measurings

a) in series the same day.
b) on different days at shorter or longer intervals.
c) the measuring accuracy in ear measurements.

2. Examination of possible causes of changes of the impedance of the normal ear.

a) Pressure in the middle ear.
b) The intra-aural muscles.

B. Measurings on different ears — The normal material.

A. MEASURINGS ON THE SAME EAR

1. AT REPEATED MEASURINGS ON THE SAME EAR

there is a possibility of a dispersion of the results due to the following causes:

1) The measuring errors of the measuring apparatus, which, as previously mentioned, are very small, if adjustment of the frequencies is provided for.

2) Sources of error mentioned in the previous chapter.

3) Changes in the vibrating efficiency of the sound conducting apparatus.

As the errors arising in connecting the apparatus to the ear in most cases can be made small, it should be expected that the difference in Abs. exceeding a few %, and the differences of Phase greater than corresponding to a change of the distance between tube and drum of a few mm., should be due to factors in or medial to the drum, which changes its Imp. How great a part of the dispersion found is due to measuring errors and how great a part is due to changes of the Imp. is not possible to ascertain.

It would be best if a series of measurings could first be made on different ears, the Imp. of which might reasonably be regarded as constant.

This is the case with ears with conduction affections, but the Imp. is here usually so low that an exact determination of it, as previously mentioned, is not possible. Several measurings were made on 2 such ears with a relative high Abs.

No. 26 left ear has previously been used (Fig. 8, p. 85). The mean value and dispersion for the 10 measurings with the small olive (the single deviating result not included) is for Abs. 12 $\pm$ 3 %, for the Phase $-34 \pm 3°$.

No. 33 right ear. Diagnosis: Occlusio tubae. The figures also for 10 measurings are: Abs. 17 $\pm$ 2 %, Phase $-28 \pm 1°$.

The dispersion in these cases with predominant probability is due alone to the measuring errors.

1 a. *Repeated measurings in series.* Such measurings were made on several normal ears. They may be made in different ways:

1) A series of successive measurings without removing the apparatus but with an interruption of the tone after each measuring.

2) The apparatus between two measurings is removed from the olive the position of which is corrected before the apparatus is connected again.

3) A series of measurings with removal and replacing of the same olive.

4) A new olive fitted and inserted before each measuring. To 1). This method differs from the others as there, as previously mentioned, could be a possibility of a change of Phase due to change of temperature in the tube. At the frequencies which have been used here and within the spaces of time which these measurings required, about 10 mins., it was impossible for this reason to demonstrate a gradual change of the Phase in a definite direction.

At successive measurings (just after each other) nearly all the results will be alike. If there elapses some time between the measurings, there will frequently arise differences the cause of which often may be demonstrated to be a displacement of the olive on account of movement of the patient's head. For the same reason a gradual change of the Phase or Abs. in a certain direction may be found but again get the original value when the position is corrected without interruption of the connection between the measuring apparatus and the ear. This would naturally not be the case, if such a change of Phase was due to change of the temperature in the tube.

That almost the same results as a rule are obtained by successive measurings is seen from the many measurements which have been made just before and just after the response of the tensor muscle has been elicited. The mean difference between Abs. and Phase just before and just after is — both at 512 and 768 Hz. about 1 % and 1 ° (calculated as $\sqrt{\frac{\Sigma(\text{diff})^2}{n}}$, at 26 reflex responses elicited on 17 normal ears). The same holds for ears with perception affections.

This method can be used only in case of quickly appearing changes, generally speaking in experimentally caused changes

of Imp. f. i. just at the elicitation of the muscle reflex (p. 114) or change of the pressure in the middle ear (p. 99), but in return it permits of determinating very small changes.

For examinations of variations, which it will be of interest to examine throughout longer periods or at longer intervals, one of the other methods must be used. To 2), 3), and 4). These three methods are naturally in principle equal and must afford the same result, when carried out carefully enough. They are used indiscriminately in the serial measurements recorded in Table 4. In one single case (No. 24) a new olive was fitted in for each of the ten measurements however. All the measurements were made on suitable ears, i. e. ears with so wide a meatus that the tube could be inserted right up to the bony meatus. (Narrow auditory canals cause, as mentioned, difficulties which have been very little regarded in this work).

In Table 4 is shown number of the case, mean value, and the standard deviation for Abs. and Phase as well as the number of measurings on each ear with 512 Hz.).

Table 4. Serial measurings on the same normal ears.

		Absorption		Phase		
Pt. No.	Ear.	$\overline{X}_a$	s	$-\overline{X}_\varphi$	s	n
18	L.	34%	± 3%	29°	± 1°	12
24	L.	49%	± 4%	37°	± 2°	10
25	L.	50%	± 1%	40°	± 2°	10
25	R.	34%	± 3%	46°	± 2°	9
31	L.	35%	± 3%	37°	± 2°	8
35	R.	37%	± 2%	32°	± 1°	8
35	L.	36%	± 1%	38°	± 1°	5

The mean dispersion in all 62 measurements was:

$$s_{\text{Abs}} = \pm 2.6\,\% \qquad s_{\text{Phase}} = \pm 1.6\,°.$$

In spite of the fact that the sources of error on connecting the apparatus to the meatus chiefly influence the Phase, the dispersion is found to be smallest for it and so small that about 95% of the measurements are within ± 3,2° ($2 \cdot s$). This corresponds to the variation which necessarily must be obtained on account of inevitable small differences in the

position of the olive (p. 77). The dispersion of Abs. is greater (about 95 % of the measurements are within $\pm$ 5.2 °). As the sources of error at the connection, as shown, but slightly affect the Abs. it is most probable that the greater spreading chiefly is due to the adjustment precision, as previously mentioned, being greater for the felt tube — which chiefly changes the Phase — than for the piston which changes the Abs., but it cannot be excluded that also small changes of the Abs. of the sound conduction apparatus itself may contribute.

1 b. *Repeated measurings on the same ear on different days.* By examples it will be shown that the same values of Abs. and Phase most often are found, but sometimes differences which cannot be explained by the measuring errors.

On the other hand examinations were not made of the frequency of occurrence of such differences at repeated measurements on the same ear or on different normal ears.

In Table 5 is for 512 Hz. shown the mean value of measurements on several normal ears on 2—3 different days, where judging by the above it must be assumed that the difference is due to the measuring errors. In most cases there is only a difference of a few per cent on the different days. The greatest difference is 8 %. The measurements are only recorded for

Table 5. Measurements on the same normal ears on different days. (2 patients, Nos. 2 and 33, with an contralateral pathological ear are included. Otherwise the ears of the normal material have been used). — 512 Hz.

Pt.	Ear.	Date	Abs.	Phase (— ϑ)	Pt.	Ear.	Date	Abs.	Phase (— ϑ)
1	L.	5/4 41	34 %	37 °	35	L.	6/1 42	31 %	34 °
-		21/4 -	26 %	37 °	-		7/1 -	35 %	37 °
-		22/4 -	34 %	41 °	33	L.	14/1 -	32 %	28 °
2	R.	22/4 -	34 %	42 °	-		15/1 -	32 %	28 °
-		24/4 -	34 %	35 °	-		28/1 -	30 %	29 °
6	R.	15/5 -	35 %	44 °	43	R.	6/2 -	26 %	29 °
-		19/5 -	34 %	45 °	-		23/2 -	29 %	30 °
9	L.	23/5 -	42 %	37 °	43	L.	6/2 -	23 %	33 °
-		30/5 -	46 %	30 °	-		23/2 -	23 %	28 °
15	L.	8/9 -	20 %	27 °	56	L.	27/4 -	39 %	37 °
-		12/9 -	20 %	32 °	-		28/4 -	40 %	37 °
25	R.	20/11 -	33 %	46 °	87	R.	21/9 -	43 %	25 °
-		6/7 42	28 %	40 °	-		24/9 -	43 %	25 °

512 Hz., but the other frequencies on the whole give the same results.

At measurings of the following normal ears reliable differences were found on different days however.

On No. 18 twenty-two measurings on the left ear were made on 3 different days. During the first two days, 21/10 and 22/10, about 10 measurings were made in all which were about equal. On the last day, 31/10 i. e. one week later, twelve measurings were made, which differ from the measurings of the first two days:

Pt. No.	Ear	Date	$\bar{X}_a$	s	$-\bar{X}_\varphi$	s	n
18	L.	21/10 41	34%	± 3%	29°	± 1°	10
		22/10					
		30/10 41	43%	± 2%	34°	± 3°	12

The dispersion of the measurements is very small and there is now a sure difference between the mean values, as the difference between them is more than 3 times the mean error on the difference.

[As far as the Abs. is concerned $t = 9.5$, being 9.0 for the Phase. Reality condition: $t = 2.485$. 1 % level].

The same applies to No. 25, left ear. Here the figures for 2 days with an interval of a good six months are:

Pt. No.	Ear	Date	$\bar{X}_a$	s_a	$-\bar{X}_\varphi$	s	n
25	L.	19/11 41	50%	± 1%	40°	± 2°	10
		6/7 42	34%		39°		3

The Phase is here the same, but there is a considerable difference in Abs. There was no difference either in Abs. or Phase on the right ear (see Table 5). The hearing for the deeper tones was normal (audiogram 6/7 42). On the left ear of No. 17, 34 measurements were made on 5 different days.

The measuring results are recorded in the usual co-ordination system (Fig. 10). At the measurements performed on the last day (22/10) by using olives of different sizes and placing them far inside and farther outward in the meatus it was examined how great a dispersion could thus be got. In Fig. 10 can

directly be seen that the dispersion chiefly covers the total dispersion for all the 5 days, but it does not explain why the Abs. on 2/10 is about 10 % higher than on the other days.

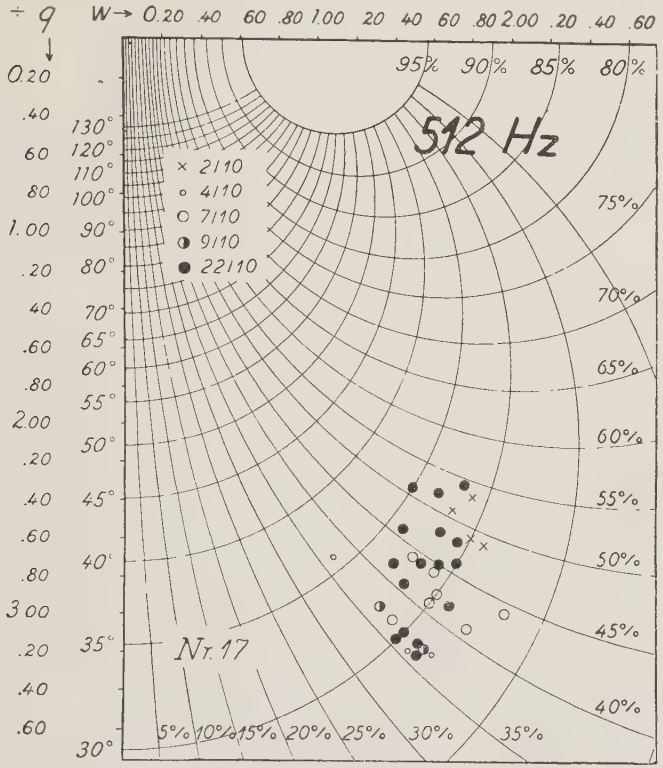


Fig. 10. The dispersion of a series of measurements on a normal ear by placing the olive in different places in the meatus.

On this day a mean value of Abs. of 50 % is found (4 measurements with a newly fitted olive each time). The mean value of 13 measurements (4/10, 7/10, and 9/10) is 39 %. 11 measurements on 22/10 are also somewhere about this value.

The higher Abs. was that day only found in using a big olive far outward in the meatus or a smaller olive which was gradually placed farther out. (Cf. also Fig. 9, where the same measurements have been used). At the measurements on 2/10

this was not the case. The olive was inserted far into the meatus and the 4 measurements lie very close to each other.

It must therefore be assumed that the difference is real and that Abs. on 2/10 has been about 10 % higher than on the other days. The mean value of the Phase is equal for all the days. The figures appear from the following table:

Pt. No.	Ear	Date	$\bar{X}_a$	s_a	$-\bar{X}_\vartheta$	s_ϑ	n
17	L.	2/10 41	50 %	± 2 %	30°	± 1°	4
		4/10-7/10					
		9/10 41	39 %	± 3 %	30°	± 2°	13
		22/10 41	45 %	± 6 %	32°	± 2°	17
		22/10 41	41 %	± 4 %	30°	± 1°	11

In the lowest row the 6 measurements on 22/10 with the highest Abs. are not included. The measurements lie then, as is also clearly seen in Fig. 10, exactly as the measurements on the 3 previous days.

The repeated measurements on this ear further show in conformity with the results of the serial measurements on the same normal ear — with how great an accuracy the measuring results may be reproduced, if the above-mentioned directions are observed.

1 c. *The measuring accuracy in ear measurements.* As is seen above (p. 92) there is a difference in the measuring accuracy between measurements on the same ear immediately after each other without breaking the connection between ears and measuring apparatus and measurements made according to the other methods mentioned on p. 93.

In the first named case the measuring precision is very great. The mean difference between 2 successive measurements for 512 and 768 Hz. is about 1 % and 1 °.

By the other methods, 2), 3), and 4) the measuring errors assert themselves somewhat more. The mean error of the single measurement for 512 Hz. is ± 2.6 % and ± 1.6 °.

2. EXAMINATIONS OF POSSIBLE CAUSES OF THE DIFFERENCES IN THE IMPEDANCE SOMETIMES OCCURRING AT REPEATED MEASUREMENTS ON NORMAL EARS

Both at serial measurements and particularly at measurements on different days, variations in the Imp. may occur, which are not due to sources of error outside the ear drum. An examination of these deviations on the normal ear, the cause of which certainly above all must be looked for in the middle ear pressure and in the conditions of contraction or tonus of the intra-aural muscles, gradually lead to an examination of pathological conditions.

In the following will in addition to normal ears also be used examples which might possibly be characterized as pathological besides reliably pathologic cases which especially illustrate the examined conditions.

2 a. *The pressure in the middle ear.*

That differences between pressure in the middle ear and the atmospheric pressure influence the mobility of the sound conduction apparatus and consequently the hearing, has been demonstrated by several investigators.

The hearing loss may easily be detected with the help of Siebenman's test (listening to the tone of a tuning-fork during the Valsalva test) (change of the pressure of the middle ear) or with the help of Dishoeck's pneumophone (see below) (change of the pressure in the meatus). Dishoeck has examined the hearing audiometrically at different — positive and negative — pressure in the meatus. For 512—768 Hz. he found at a *positive* pressure of 20 cm. H_2O a hearing loss of 5—10 db, at + 60 cm. about 20 db, at + 200 cm. about 28 db, and at a *negative pressure* of 20 cm H_2O about 2 db, at — 60 cm. about 10 db.

Increase of the Imp. on an increase of the pressure in the external meatus was demonstrated by *v. Békésy*, who at the same time demonstrated a subjective change of the sound intensity of about the same range of magnitude.

In order to find out whether it was possible, with the help

of the method here employed, to demonstrate changes of Imp. by changing the pressure in the middle ear some preliminary experiments were made.

At first some preparation experiments were made. Fresh temporal bones are well suited for such examinations as the elasticity coefficient at any rate during the first 24 hours post mortem does not essentially deviate from that of the living ear (*O. Frank, Dahmann*). The Imp. of the drum gradually increases and, after a couple of days, often reaches 5—10 times greater values. This increase is mainly due to desiccation of the drum, which therefore must be prevented. There does not on the other hand occur any change of the elasticity of the ligaments and bands in the middle ear, which is moreover less exposed to desiccation than the thin drum (*v. Békésy*).

The examinations were performed on the same day as the autopsy. It was tried to prevent desiccation by keeping the preparations wrapped in a wet cloth in a refrigerator. During the experiments the humidity was maintained by means of spray. Nevertheless there may — probably on account of other post-mortal changes — occur some changes in the Imp. so that it is difficult to reproduce an experiment after the lapse of a certain period, that means to say, it may be repeated it is true, but from another initial value af Imp., and it is not always certain that it is possible to get exactly this value at the end of the experiment. These sources of error are however small in comparison with the changes which are to be examined.

In order to produce changes of pressure in the middle ear a tube is applied fitted tight either in the tuba or in a hole fraised in the tegmen tympani after closure of tuba. The acoustic bridge is connected to the preparation with the help of a tube inserted in the meatus in the same way and at the same place as during the examinations on living persons.

In Fig. 11 the change of the Imp. is noted for 768 Hz. when the pressure in the tympanic cavity is changed cm. by cm. H_2O in positive or negative direction.

It is seen that very considerable changes in Abs. as well as in Phase are obtained by these small changes of pressure.

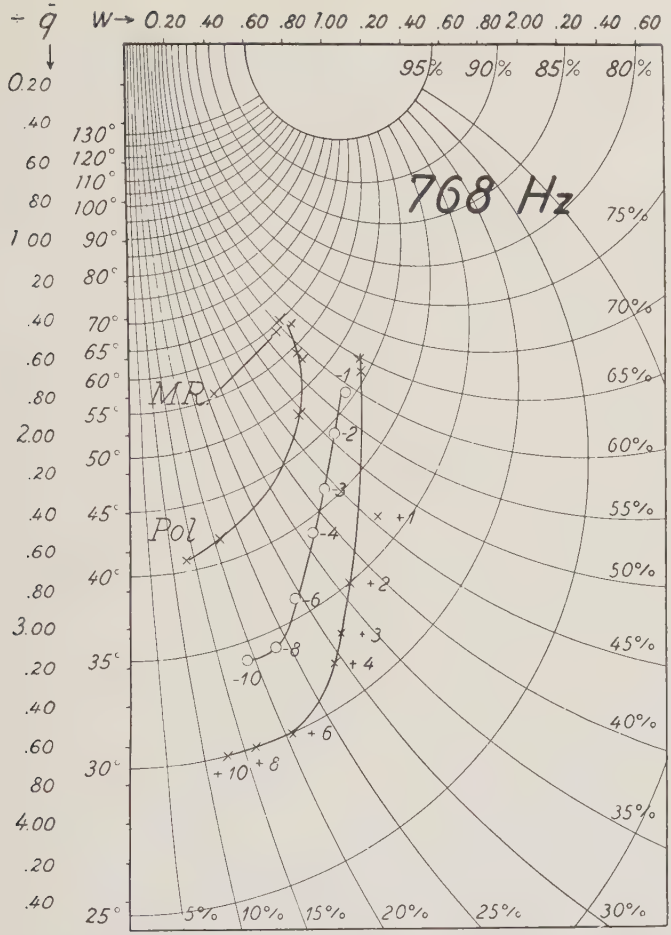


Fig. 11. The change of impedance when the pressure in the middle ear of an ear preparation is changed in positive or negative direction (the two lowermost curves. The numbers indicate the pressure in cm H_2O). Pol. means the Imp. after a Politzer air douche on a normal test person, and the curve, how, after a couple of deglutitions, it returns to its initial value. M. R. indicates the change after an acoustic reflex contraction of the intra-aural muscles.

Experiments on other preparations have given similar results. At first there is a change both of Abs. and Phase for negative as well as positive pressure, later only of Abs. Considering

the components w and q of the Imp. there occurs at first a strong increase of the numerical value of q while w is only slightly changed. When the difference of pressure increases, w gradually changes more and more, i. e. the numerical value of the Imp. increases, and the Imp. changes gradually in the direction of a pure reactance.

On examinations of the living ear changes in the same direction as at the preparation experiments are obtained. In Fig. 11, above the curves of the preparation experiment the Imp. values are plotted before and after Politzer's air douche performed on an ear of a person from the normal material (No. 96). Abs. and Phase at the beginning of the experiment were 58 % and — 59 ° respectively. The air douche was given twice. After the first douche the Imp. was 21 % and the Phase — 42 °. After two deglutitions these values returned to 61 % and — 60 °. The intermediate stage, after the first swallowing, is at 58 % and — 53 °. After the second air douche the Imp. dropped to 13 % and — 41 °.With intermediate stages at (49 %, — 48 °) and (59 %, — 54 °) after 3 swallowings it returns to 62 % and — 58 °.

The change of the Imp. is absolutely the same as at the preparation experiment. When the Imp. returns to the initial value, the greatest change naturally occurs after the first swallowing. In other cases no change occurred, while sometimes the Imp. became normal immediately after the first deglutition.

This is the case in No. 25 (likewise normal). After a Politzer air douche is obtained a change of the Imp. from 51 % and — 41 ° to 23 % and — 28 °. After a deglutition the Imp. is 50 %, — 37 °, i. e. practically the same value as before.

The extent of these changes naturally depends on the air pressure applied and may be difficult to reproduce, but the direction of change of Imp. always is the same. Only a slight over-pressure was used, and the air douche was given very cautiously so as to prevent any movement of the patient's head, the ear during the whole experiment being connected to the acoustic bridge.

Tornbee's experiment gives a change in the same direction, but less pronounced. The swallowing indeed was only done

at a slight under-pressure. On a normal ear (No. 6) the Imp. for 768 Hz. prior to the experiment was found to be 52 %, — 73 °, immediately after Toynbee's experiments 37 %, — 62 °, after swallowing 52 %, — 70 °. This likewise corresponds chiefly to a change of the reactance.

At the suddenly produced positive as well as negative difference of pressure between the air inside and outside the middle ear the test subjects experience a feeling of obstruction, but the hearing at the frequencies used at the Imp. measuring are not or only slightly affected by these small differences of pressure.

On the first mentioned person (No. 96) where a considerable decrease of the Abs. occurred the hearing before and after an air douche was determined in a sound proof room, the douche both by the writer and the test person being considered to be of the same strength as at the Imp. measuring. The threshold value for the used frequency 768 Hz. prior to the air douche was 0 db, after the air douche during the sensation of obstruction 5 db, i. e. a doubtful hearing loss of a range of magnitude corresponding to the decrease of the quantity of energy absorbed. The change of the quantity of energy absorbed was calculated from u respectively 6 and 8 db after the first and second air douche.

These isolated experiments show that the proportion between the pressure in the middle ear and the atmospheric pressure is of great importance for the measured Imp. as rather small differences of pressure not only give measurable but even considerable differences of the Imp.

If such differences of pressure can occur on the normal ear, they may be reflected in the measured Imp. and thereby give rise to differences in the measurements, both repeated measurements on the same ear and on comparison between right and left ear.

Therefore it is necessary to examine the normal conditions of pressure.

The function of the Eustachian tuba and, thus, the middle ear pressure under normal as well as pathological conditions, has recently been the subject of thorough investigations by a

number of authors, to the last of which, *Zöllner*'s large monograph, the reader is referred. Below will be mentioned what is of greatest interest for the present investigations.

Zöllner on a large material has shown that a slighter or severer occlusion of tuba may be found on normal ears without there being any symptoms. In 16 per cent of 110 aviators examined the tuba opened on one side or on both sides — under deglutition — in response to pressure in the rhinopharynx amounting to 5 cm. H_2O = 4 mm. Hg., mostly 10—20 mm. Hg., and in one case, not till there was a pressure of 60 mm. Hg. without there being any ear symptoms. Audition was normal. In some of those men the reduced permeability had existed for several weeks without causing any symptoms. The majority of those 16 per cent of aviators presented slighter or severer catarrhal conditions of the nasal and pharyngeal mucous membranes.

Lennart Holmgren in experiments on dogs — to substantiate the Politzer — Zaufal — Bezold theory about hydrops ex vacuo has shown that, after closure of the tuba, a negative pressure in the middle ear may develop after a certain number of days (and in some cases a transudate).

Dishoeck and later *van den Borg*, with the aid of the pneumophone have shown that a negative pressure in the middle ear often may be found in normal persons — without giving symptoms. *Van den Borg* on examining 500 school children found 22 with a considerable negative pressure in the middle ear (the hearing best at an under-pressure in the auditory canal of more than 20 cm. H_2O) but normal audiogram. *Dishoeck* reports that there sometimes is a considerable difference between right and left ear of the same person.

After these findings, substantiating each other, it is to be anticipated that measurements on the two ears of the same person as well as measurements of the same ear on different days sometimes will disclose differences of Imp.

Inversely may a number of found differences probably be explained in this way. An examination hereof has only been made on a small scale.

An example of the change of the Imp. by a permanently patent tuba may be mentioned however.

Patient No. 51, W. 44 years. Diagnosis: Tuba aperta dxt. — Otitis dxt. + sin. seq. On the right ear there is a large thin cicatrix in the drum. It moves during ordinary respiration inwards and outwards at in- and exspiration. In the left ear is found a large defect in pars tensa. No pus. Pharynx and rhinopharynx: normal.

The hearing on the right ear is reduced 40 db., on the left 85 db. for 512 and 1024 Hz.

Impedance measuring (19/3 42):

	Right ear				Left ear			
	a	$v = -\vartheta^0$	$\bar{w}$	$-\bar{q}$	a	$v = -\vartheta^0$	$\bar{w}$	$-\bar{q}$
512	31	55	43	185	12	36	34	306
768	45	89	30	98	12	48	20	224
1145	58	144	24	31	15	66	14	154
768	21	48	Pressure with closing of the nostrils.					
768	30	67	Cessation of the pressure.					
768	44	89	Ordinary respiration.					
768	23	49	Pressure with closing of the nostrils.					
768	49	90	Ordinary respiration.					
768	29	75	Suction with closing of the nostrils.					
768	45	89	Ordinary respiration.					

There is a considerable difference in the Imp. on the two ears, partly the Abs. is 3—4 times higher on the right than on the left ear, partly there is a very considerable difference of Phase. As will be seen from the following, the Phase for the right ear for all frequencies is on the upper border of the range of the normal values. There is a question of a pathological ear, but the values are even more distant from and in the opposite direction of what would be expected in an ear with conduction affection and intact drum.

At pressure with closing of the nostrils (positive Valsava test) it is seen that the Imp. of the right ear moves downward to the vicinity of that of the left ear.

The completely open tuba which is rare — Zöllner only found it in $3^0/_{00}$ of 2000 examined airmen — changes in a high degree the Imp. of the drum, the Abs. as well as the Phase becoming greater, the numerical value of the Imp. considerably smaller. The change is naturally explained

through the changed accoustical conditions in the middle ear because of the free communication with the atmospheric air.

How great the difference becomes on an ear with a perfectly normal drum there has not been any opportunity of examining.

There were examined some single patients with tubal occlusion whose hearing improved or became normal after an air douche. The Abs. became higher, but in none of these few cases (not even in the case of the drum being reactionless) did the Imp. become normal, probably because there was a catarrhal otitis besides.

The following case tends to illustrate this:

Patient No. 95. W. 19 years. Diagnosis: Occlusio tubarum — otitis catarrhalis acuta dpl. On catching cold her ears tend to close and her hearing is reduced. Sometimes slight pains. Never discharge. Usually disappears spontaneously with the cold.

During the last 3—4 days of an attack of cold the same symptoms recur.

Aures: Drums red, slightly retracted. No signs of fluid behind the drums. Pharynx and rhinopharynx: Nothing abnormal except redness of the mucosa.

Audiogram (9/10 42):

		128	256	512	1024	2048	4096	8192
Air conduction	R. ear	30	35	35	40	25	40	35
-	L. -	25	30	30	30	25	30	35
Bone -	R. -		0	0	0	5	25	25
- -	L. -		5	0	0	5	15	5

After Politzer's air douche (made after the 1st Imp. measuring).

Air conduction	R. ear	15	20	20	15	10	25	25
- -	L. -	10	15	15	10	0	15	20

Impedance measuring (9/10 42) (before Politzer's air douche):

	Right ear					Left ear				
	a	v	$\bar{w}$	$-\bar{q}$	u	a	v	$\bar{w}$	$-\bar{q}$	u
512	3	29	14	385	0.9	5	28	22	400	1.4
768	13	37	35	295	4.0	11	33	37	335	3.3
1145	18	39	44	278	5.5	23	35	70	303	7.0

512 and 768: No change on swallowing against a pressure in the rhinopharynx of about 30 cm. H_2O. Muscle reflex: negative.

After Politzer's air douche:

512	15	24	92	454	4.3	19	23	126	460	5.5
768	25	34	80	310	8.0	27	31	104	333	8.5
1145	23	36	66	295	7.0	26	35	79	299	8.0

At the first Imp. measurings the Abs. was very low, and also the Phase was very small. Corresponding to this there was a reduction of hearing of 30—40 db. Tuba does not open on swallowing nor at a moderate over-pressure in the rhinopharynx. Only at the higher pressure through Politzer's air douche could air be got into the middle ear. After that an obvious increase of the Abs. is found immediately but the Phase is only slightly changed and in the opposite direction of what would be expected. *u* has become greater as an expression of the increased sound absorption. Corresponding to this the hearing has improved somewhat but just as little as the Imp. has it become normal. The increase of the Imp. (and loss of hearing) may thus not have been caused only by an under-pressure in the middle ear, but f. i. catarrhal changes of the mucosa must have been concurrent.

It is seen that the Imp. in this patient in regard to the Abs. — as well as the Phase — was changed in the opposite direction of what was the case in the previous patient. As an example of tubal occlusion the case is bad in as much as it is complicated with catarrhal otitis. It is not even possible with certainty to say, if there has on the whole been an under-pressure. It is possible that the change of the Imp. (and improvement of the hearing) was only due to the conduction apparatus being fixed f. i. by some secretion and was mobilised by the air douche.

On the basis of these few examined patients it is naturally impossible to form an opinion about the occurrence of the pure tubal occlusion with subsequent under-pressure in the middle ear as only cause of a reduction of hearing (lastly discussed in the Scandinavian literature by L. Holmgren and Blegvad) but the Imp. measuring before and after air douche should be able to contribute essentially to the solution of the question.

On the whole it would be worth while to continue these investigations in the permeability of the tube and the middle ear pressure with a combination of *Zöllner*'s and *Dishoeck*'s examination methods with the acoustic bridge. It can be done after the following plan:

1. Examination of the hearing (audiogram).

2. Impedance measuring with examination of the muscle reflex (which is discussed in the following).

3. Examination of the middle ear pressure according to *Dishoeck*'s method which, briefly, is *Gelle*'s test used as measuring method, i. e. examination of the hearing at different positive and negative pressure in the auditory canal based on the presumption that the tone must be heard most clearly when the pressure is equal on both sides of the drum. The middle ear pressure is thus presumed to be equivalent to the pressure in the meatus when the tone which is conducted to the ear through the meatus is heard most clearly.

Dishoeck's apparatus is the acoustic bridge itself. The one auscultation tube need merely be put into connection with a balloon, and the other with a manometer. The air-tight connection to the ear has been described before, the air-tight closure of the other end of the acoustic bridge can be obtained by pushing the felt tube and piston quite down to the bottom and fixing small rubber discs around the felt tube and piston close to their collars. Because of the symmetrical construction of the bridge the pressure must be changed equally on both sides of the telephone membrane.

4. Finally determination of the permeability of the tuba according to *Zöllner*'s method. It is in principle a graduated and measurable Politzer air douche.

As indicator of the air reaching the middle ear *Zöllner* uses the movement of the drum, which is observed in an ear-microscope. The Imp. of the drum or only its change measured or indicated by the acoustic bridge is a far safer method for obtaining information about this, and it is moreover easy to get to know whether the pressure in the middle ear returns to normal after one or more swallowings.

5. Eventually renewed audiogram. The description of this series may, perhaps, sound complicated, but if it is arranged practically, it can be done in a short time and will collectively give information about the condition of the tuba and middle ear, which cannot be got in any other way.

2 b. *The contraction of the intra-aural muscles.*

Below will be reported some examinations of the change of Imp. at the acoustic-reflex contraction of the intra-aural muscles (muscle reflex: M. R.).

It is impossible to enter into the fairly extensive literature which treats of the function of the intra-aural muscles. Synoptic accounts of such were given by *Kreidl, Schaefer, Schaefer and Giesswein, Mangold, Lüscher, Perlman and Case, and others.* It will however certainly be opportune to summarize the main points, which with regard to the literature before 1926 are cited from the above-mentioned manuals and to quote the most important results of the latest investigations.

For many years two hypotheses about the function of the two intra-aural muscles — the tensor tympani and the stapedius muscle have faced each other.

1. *According to the accommodation hypothesis* the two muscles constitute an accommodation apparatus which adjusts the sound conduction apparatus to the best possible sound absorption, the muscles being assumed to act as antagonists morphologically as well as functionally. The tensor tympani has a damping, the stapedius an intensifying effect, i. e. the sound conduction takes place best at a certain contraction of the stapedius muscle.

2. *The protection hypothesis* assumes that both muscles by their contraction protect the ear against strong sounds by reducing the sound conduction.

Supporters of either theory are evident from the literature cited above.

The effect of the tensor tympani which stretches the drum, resulting in an inward movement of the manubrium mallei and the drum was already demonstrated by *Politzer* on autopsy material. On this has been no disagreement. *Politzer* has also shown that the stapedius by its contraction must turn the base of stapes round its posterior pole, whereby the stirrup is drawn slightly away from the labyrinth and thus in this respect acts as an antagonist to the tensor.

Lucae and *Ostmann* are of the opinion that simultaneously there is an outward movement of the drum.

Thus while there is agreement about the physiological effect of the tensor tympani, disagreement prevails with regard to the result of the contraction of the stapedius.

In a series of examinations of the living ear according to Lücher's below mentioned observation, the function of the stapedius contraction is now considerably more clear than the mode of action of the tensor tympani, about which very little is know besides the fact that it stretches the drum by its contraction.

On the living normal ear one could only from an eventual movement of the drum infer a muscle contraction. On finding an inward movement of the drum it is warrantable to assume a contraction of the tensor.

Such an inward movement of the drum has been observed by several authors in persons who voluntarily could contract the tensor (*Luschka, Lucae, Politzer, Schrapinger, Köhler, Mangold, Cemach, Waar*). In response to strong sound irritants the inward movement has been observed by *Ostmann, Mangold* and *Cemach,* but they stress the difficulty of observation because of the minimal excurtions. *Mangold* (1913) on a suitable test person has photomanometrically registered the air pressure oscillations in the external auditory canal on reflectory and voluntary contraction of the tensor tympani.

Trendelenburg has registered the muscle tone (1930).

In opposition to this *Waar* (1923) by examining 12 persons under considerable magnification has never detected a movement of the drum, not even on the strongest sound irritants. *Lüscher* regards this examination technique as absolutely reliable, because in this way it is possible reliably to ascertain the slightest movements. The movement of the muscle itself has never been observed. A movement of the drum on contraction of the stapedius muscle has never been observed, and *Lucae*'s and *Ostmann*'s observations have never been confirmed.

In animal experiments and in the cases, in which the movement of the drum could be observed on Man it could be elicited partly by acoustic irritants, partly as conditional reflex (*Kato*) and finally by inadequate sensitive irritants (*Eckstein, Kato*).

The reflex always appears bilaterally even in response to a unilateral irritant (*Mangold, Kato*).

Lüscher in 1929 has for the first time — on Man — directly observed and examined the contractions of the stapedius through a traumatic perforation upwards and posteriorly on an otherwise normal ear. Subsequently other authors have confirmed and extended *Lüscher*'s examinations (*Lindsay, Kobrak and Perlman* 1936, *Potter* 1936, *Perlman* 1938, *Perlman and Case* 1939).

The results of these examinations, which to a great extent have contributed to the elucidation of the function of the stapedius muscle, are briefly as follows:

The reflex can be elicited by pure tones, in Lüscher's 2 cases respectively from 90 to 14000 Hz. and from 650 to 12000 Hz. It shows considerable individual variations both with regard to the range of tones and to the intensity.

The threshold for the reflex, i. e. the smallest sound intensity which can elicit it, has been determined at 65—85 db above the threshold of hearing (*Lindsay* et alii).

The intensity of contraction is in quantitive proportion to the acoustic irritant. At weak irritants only a single contraction occurs, at stronger irritants, several contractions are observed, and very strong irritants finally give rise to a condition of tonic contraction.

It is more easily elicited by noise. The stapedius reflex can be fatigued, and after 1—$1^1/_2$ min. a reflex deafness occurs. "The fatigue" disappears a few minutes after cessation of the tone. "The fatigue" must strike the sensitive side of the reflex arc, for it only appears after that special tone. A tone of another frequency immediately gives rise to a renewed contraction of the muscle.

A comparison between the reflex deafness and perception fatigue for a tone shows agreement, as the latter also reaches its maximum after a couple of minutes. *Lüscher* therefore assumes 2 principally different regulation mechanisms:

1) a neuro-muscular apparatus (the muscle reflex) which reacts instantaneously and regulates the conduction of the irritant.

2) a change — "Umstimmung", "adaptation" of the perception apparatus, which only develops after some time.

There is complete analogy with the pupillary function of the eye and the light-dark adaptation.

A voluntary stapedius contraction has never been observed.

All these examinations are greatly in favour of the protection hypothesis. They make it highly probable that also the contraction of the stapedius muscle reduces the sound conduction. The two muscles act morphologically as antagonists but physiologically as synergists.

Whereas the function of the stapedius now is fairly well elucidated very little is as yet known about the function of the tensor tympani in Man.

Kato and later Kobrak in animal experiments have shown that the stapedius reflex is the most sensitive and always appears first. *Lüscher*'s observations on Man point in the same direction, even though they do not prove it. *Lüscher* therefore assumes that either only stapedius or also both muscles take part in the reflex contraction. One really does not know, if there appear regular tensor reflexes in Man or if the protection mechanism only consists of the stapedius reflex. In that case it would be natural to expect inactivity atrophy of tensor, which is not found, therefore it is most probable that there occur regular tensor reflexes also.

Most of the mentioned authors who have observed tensor reflexes have done so on individuals who were also able to contract the tensor tympani voluntarily. This is something which differs from the normal, and it may be assumed that an abnormal preponderance of the tensor tympani is responsible for the inward movement, eventually a disturbance of the coordination between the two muscles (*Lüscher*). That there has otherwise so seldom been observed an inward movement of the manubrium mallei and the tympanic membrane may be due to simultaneous contraction of the antagonistically acting stapedius muscle.

Thus after an agreement gradually having been reached about the effect of the contraction of the two muscles, the

Imp. measuring has brought a new difficulty with regard to the explanation of the purpose of the contraction.

Geffcken by Imp. measuring has shown that a voluntary tensor contraction only slightly changes the vibration faculty of the drum.

v. Békésy on a fresh temporal bone, where all muscles due to rigor mortis are very tense, finds that the vibration faculty of the drum and the ossicles at the utmost is reduced by 1/3. *v. Békésy therefore assumes that the tensor contraction hardly can be an effective means of protection against strong sounds.*

In connection with his demonstration of a quite different mechanism for the protection of the ear against too great pressure amplitudes he (1936) sets forth a new explanation of the function of the intra-aural muscles.

Briefly described the protection mechanism consists of a change of the vibration axis of stapes so that, at great sound pressures, it almost coincides with the longitudinal axis of basis stapedis. Thereby the fluid in the inner ear is merely dislocated from the upper half of the base of stapes to the lower half, without fluid being pressed into the cochlea. In that way the vibrations of the drum are not transferred to the perilymph. The transition to this from the normal way of vibrating is facilitated by the ossicles not moving around a fixed axis, but around a point which is formed by contact of crus breve incudis with the wall of the middle ear. The unstable equilibrium of the ossicles and the articulation between the incus and stapes thus constitute a necessary link in the protective mechanism, but it implies the difficulty that a "Klirrfaktor" (i. e. a non-linear distortion) easily occurs by transmission of vibrations from one ossicle to the other, namely, if the pressure, which keeps them together, is reduced below the acceleration force which appears during the vibration.

If the amplitudes are small the elastic ligaments are sufficient.

At greater amplitudes the muscles come into function. They press the stapes against incus and simultaneously stretch the other ligaments.

This explanation of the function of the intra-aural muscles is in agreement with the fact that the muscles contract them-

selves particularly at high tones, and that the contraction increases at increasing sound pressure, because the acceleration force at sinus-shaped vibrations is proportional to the vibration amplitude and the square of the frequency. *v. Békésy* has further shown that the muscles may contract with a force of a range of magnitude corresponding to the magnitude of the acceleration forces in question.

THE CONTRACTION OF THE INTRA-AURAL MUSCLES. OWN EXAMINATIONS

The acoustic reflex contraction.

The contraction of the intra-aural muscles gives rise to a very distinct and usually measurable change of the Imp. of the drum.

It has been examined in such a way that an acoustic reflex contraction was elicited from the opposite ear. The acoustic bridge is connected to the one ear, and the comparison resistance is adjusted until the equilibrium is reached, i. e. silence at the listening place. By a sudden noise before the other ear a very striking reaction is usually obtained, the tone again being heard strongly. The change of the tone begins at once, but the tone does not immediately reach its maximal intensity. The change can be observed until it reaches maximum. As long as the noise lasts, the tone is heard. When the noise is interrupted, it decreases again so that the change is audible and perfect silence indicates that there is equilibrium again and the Imp. of the drum is the same as before. The noise thus produces and maintains a contraction of the muscles. (In spite of not knowing to how great an extent or whether the tensor tympany at all perticipates in the contraction the terms "The intra-aural muscles" and "the muscle reflex" are used, which thus, perhaps, only signify stapedius and the stapedius reflex). As a source of noise Bárány's noise apparatus has been used. In several cases a distinct reaction could be elicited with the noise apparatus at a distance of 30—50 cm. from the test subject's ear. In these persons it has also been possible to elicit distinct though short contractions by the stronger

sounds of the conversational voice, and especially clearly by striking a c^4 tuning-fork in the room. On other normal persons the reflex can only be elicited when the noise apparatus is put to the ear and in isolated cases it is not possible to elicit any contraction.

As a proof that it really is a muscle contraction which is elicited, the following may be mentioned:

1. That an acoustic-reflex contraction can be elicited through noise and sound by the used categories has, as mentioned, previously been shown, and also that it is elicited bilaterally even if the irritant only acts unilaterally.

2. Placing of the noise apparatus in contact with the tube of the acoustic bridge when equilibrium has been established against a fixed resistance (an "artificial ear" or a closed tube with a small hole in the closure) does not in any way change the equilibrium, not even when the noise apparatus is placed in front of but at a small distance from the hole in the tube.

3. On ears with conduction affection the reflex cannot be elicited.

4. On a patient who has a pronounced unilateral loss of hearing of the perception type, a reflex on the deaf ear, as will be shown later, can be elicited from the normal ear but not the reverse.

5. On an acutely perception-deaf person where this was the case a clear distinct reflex could, after the hearing had returned, be elicited on the normal ear from the affected ear, which was not possible before.

These conditions show with the greatest probability that it really is a muscle contraction which is elicited.

The qualitative change of the Imp. can be demonstrated with great certainty. The used transition from silence to tone is a very delicate and distinct indicator. When a reflex on the whole can be elicited the change is extraordinarily marked. Only in quite isolated cases (incl. the patient material) has there been any doubt if the reflex could be elicited or not. Information as to how, or how much the Imp. changes is not obtained in this way however.

If it is desired to determine the quantative change of the

Imp. the matter is somewhat different. This must be done by measuring the Imp. of the drum during the muscle contraction, but this causes certain difficulties.

In some persons a constant state of contraction of the muscles persisting with the noise is elicited and the comparison resistance can be adjusted to sound minimum or silence in a new position corresponding to the changed Imp. When the noise ceases, the tone naturally is heard again and the comparison resistance must be put back to its original position in order to re-establish equilibrium. In these cases a rather exact measuring can be made, which only is slightly disturbed by the noise from the noise apparatus.

In many persons however it is discovered that it is not possible to adjust the comparison resistance to silence. When the presumed equilibrium has been reached the tone is heard to vibrate synchronally with the noise from the noise apparatus. This makes the adjustment very difficult. Such a condition of more or less marked contraction occuring often the values can only be taken as an approximate valuation of the Imp. during the contraction. With another source of noise this difficulty certainly can easily be avoided, but Bárány's noise apparatus functions excellently at the qualitative test to which at present most importance has been attached. In many cases an excellent quantitative determination may be obtained, examples of which are given below.

How is the Imp. of the drum changed by the contraction of the intra-aural muscles.

Fig. 15 in the usual coordinate system shows the Imp. and its changes after the reflectoric muscle contraction on the examined normal ears at 512 Hz. Both at 512 Hz. and at the other frequencies used there chiefly is a question of a decrease of the Abs., in many cases a pure change of the Abs., in some cases also accompanied by a slight change of the Phase.

The change of the Abs. is in some cases very great, f. i. in No. 87 (from 43 to 14 %) with 512 Hz. That corresponds to a decrease of the absorbed energy quantity of 5.5 db. calculated according to *u*.

In other cases, however, it was smaller; but even small changes found at repeated measurings on the same ear, are, as previously mentioned, more significant than the differences between different ears. No. 33 shows this. There were made 17 ordinary measurings — at 512 Hz. — on 3 different days, in addition to which 4 measurings during elicitation of the muscle reflex. Below are recorded the mean value and the mean deviation for Abs. and Phase without and during muscle contraction.

	Absorption		Phase		
	$\overline{X}_a$	s	$-\overline{X}_\varphi$	s	n
Without muscle contraction	32%	± 1.3%	28°	± 1.1°	17
During muscle contraction	24%	± 1.3%	29°	± 0.8°	4

For the Abs. $t = 10.9$ (corresponding to the 1%-level t should be > 2.86 for the difference to be real). The change of energy absorption is 1.5 db.

Muscle reflex by inadequate, sensitive irritants.

No examinations have been made especially with this in view. It might be thought that the placing of the olive or the irritation of the olive at movements of the head during the measurings could elicit such a reflex. In the former case, however, it would not be discovered and for the latter reason it has never been seen.

Lüscher reports that the introduction of a glass olive gives rise to movements of the muscle. The possibility has been thought of that a very low Abs., which occasionally has been found on otherwise normal ears, might have been caused by such a muscle spasm, but it has indeed been impossible to find any clues for this presumption.

The voluntary tensor contraction.

We have had the opportunity of examining a single person who could voluntarily contract the tensor tympany. It produced a change of the Imp. in quite the same direction as at the reflex contraction, but of another size.

It is a 38 year old physician (No. 72) who has never had any ear affections. On contraction of the tensor tympani he simultaneously hears a strong humming, which also the examiner at the examination with the aid of an auscultation rubber tube could hear distinctly. How the contraction is produced he cannot explain, but he thinks that he simultaneously contracts the m. orbicularis oculi. Aures: Drums quite normal. At the voluntary tensor contraction a small reflex change at the posterior hammer fold becomes distinctly visible in the ear-microscope. At a reflectorily elicited contraction no definite change can be observed.

Audiogram.	128	512	1024	2048	8192
Air conduction R. ear	— 10	— 5	— 5	— 5	0
- - L. -	— 10	— 5	— 5	— 5	0

The threshold values for 512, 1024 and 2048 were likewise determined during the voluntary tensor contraction. No change could be demonstrated but that was dificult to decide because of the simultaneously occurring buzzing especially for the lower frequencies.

Impedance measuring:

Right ear						Left ear					
a	$v = -\vartheta^0$		$\bar{w}$	$-\bar{q}$	u	a	v	$\bar{w}$	$-\bar{q}$	u	
384	35	33	118	296		28	34	90	305		
512	60	41	135	187		41	37	113	255		
768	81	74	86	88		73	83	64	91		
1145	76	76	76	94		75	68	86	106		
512	60	41	135	187	25,4	40	37	110	258	14.0	
-	35	40	86	250	12,3	15	37	40	295	4.5	T.C.*)
-	61	41				41	37				
768	81	74	86	88	56,8	73	84	63	90	52.1	
-	67	72	69	112	39,9	39	60	47	164	16.1	T.C.*)
						73	83	64	91		
						55	72	53	124	29.1	M.R.**)

*) T.C. = Voluntary tensor contraction.
**) M.R. = Muscle reflex.

Particularly on the right ear there is a very high Abs. for all frequencies and especially at 512 Hz. a considerable difference between right and left ear. The auditory canals were relatively narrow and fairly crooked so that it was difficult to place the olives. It cannot be quite excluded that that is responsible for the difference, but it is of no importance for the changes of the Imp. which are to be measured, as it was possible

always to return to the initial values. It is also possible that the high Abs. and the difference just are related to the deviating conditions of which the voluntary tensor contraction is an expression.

After the acoustic bridge has been adjusted to equilibrium it was possible, when the voluntary muscle contraction (T. C.) was made, to hear an extraordinary distinct change, the tone now being heard very strongly. On adjustment to the changed Imp. complete silence could again be obtained.

The contraction could be kept up at the most for 20 to 30 sec. after which time it was distinctly audible how the equilibrium became unstable, probably as a sign that the muscle gradually got tired. It could be observed how the Imp. gradually returned to its initial value.

After brief periods of rest the experiment could be repeated in the same way. A reflex contraction (M. R.), as usually elicited by Bárány's noise apparatus in the opposite ear, gave a change of Imp. in the same direction but less pronounced, as the figures show. The pure change of Abs. at 512 Hz. is noticed, at 768 Hz. there is both a change of Abs. and Phase. In both cases there is, especially for the left ear, a reduction of *u*, most pronounced at the voluntary contraction.

Mangold and *Eckstein* with manometric registration also find a stronger reaction at the voluntary than at the reflectoric contraction. It is not necessary therefore to conclude that the tension of the drum is increased.

This is first shown by the Imp. measuring, but the deflexion of the manometric registration may be merely an expression of the lacking effect of stapedius and therefore a greater change of position of the drum.

Unfortunately, the simultaneous effect of the voluntary and reflectoric contraction was not examined. In the former case there is a pure tensor contraction, in the latter case a stapedius (+ tensor) contraction. It will therefore be of considerable interest to see, if a stapedius reflex can be elicited during the tensor contraction, or, inversely if the voluntary tensor contraction gives a still greater deflexion when the stapedius is contracted beforehand.

The change of Imp. itself at the voluntary tensor contraction apparently has previously only been determined by Geffcken (1934). *Geffcken* found only a slight change of the resistance component (w) which — converted with the wave resistance in air as a unit — was 2.10 before the contraction, and during it, 2.39. On the other hand there was a considerable change of the reactance (q) which, converted in the same way, before the contraction was — 0.48, during the contraction + 1.42. During the contraction u became abt. 30 % smaller.

The change of w and q is not in accordance with the changes found here, but the main result, that u becomes smaller is the same. *Geffcken* does not state at what frequency the measurings have been made.

Description of 2 cases with unilateral trigeminus paresis.

It will be natural to describe two such patients here.

The first is a 41 year old man (No. 38), who for some days has had a thumping sound before his left ear. There have not previously been any ear symptoms, and on the day of examination the sound has ceased again. The hearing had not been reduced. No vertigo.

Aures: Drums normal. Large auditory canals. *v*: 12,00/2,00. *Li*: 24/24. *Ls* (*a*): 19000/19000.

Audiogram:				128	256	512	1024	2048	4096	8192
Air conduction		R.	ear	— 10	— 10	— 5	0	0	5	0
-	-	L.	-	5	— 5	— 5	0	0	30	>95
Bone	-	R.	-		0	5	5	5	25	15
-	-	L.	-		0	0	5	5	35	

There was fairly fine and slow nystagmus towards the right. Caloric reaction was elicited equally from the two ears. W. R. negative.

The neurolgic examination disclosed anaesthesia of the skin on the whole left side of the face. The anaesthetic region reached backwards to the ear inclusively upwards to the border of the hair. Neurological diagnosis: Arachnoiditis with left trigeminus paresis.

Impedance measuring:

	Right ear				Left ear				
	a	$v = -\vartheta^0$	$\bar{w}$	$-\bar{q}$	a	$v = -\vartheta^0$	$\bar{w}$	$-\bar{q}$	
512	29	23	185	413	59	31	189	212	
-		no change			17?	32?	59?	340?	M.R.
768	48	42	18	216	75	64	93	111	
1145	50	47	96	194	80	55	117	107	

There is a considerable difference in Imp. on the two ears. The ear canals of this patient being large and fairly straight an excellent and well reproducible placing of the olive was possible. The different sources of error may be considered to have been surely eliminated.

At first is noticed the very high Abs. of the left ear homolateral to the trigeminus paresis in opposition to the Abs. on the right ear which is entirely within the normal range. The phase on the other hand is more normal on the left ear, being very small on the right ear (Fig. 12—14). This means that the Imp. itself for the right ear is very high, for the left ear is considerably smaller. The difference is mainly due to the reactance (q). The elasticity on the left ear is very small — and what is remarkable — it looks as if it is increased on the right ear.

Bárány's noise apparatus applied to the right ear gives a very considerable decrease of Abs. in the left ear. The measuring was difficult, hence the figures are only approximate. Inversely no muscle reflex on the right ear (from the left) can be elicited.

The increase of Abs. (and the decrease of Imp.) on the left ear may easily be explained by assuming a left paresis of the tensor tympani which the trigeminus paresis and the preceding ear symptoms may also suggest. The great decrease of the Abs. at the muscle reflex must be assumed to be caused only by the contraction of the stapedius muscle.

It is more difficult to explain that the muscle reflex cannot be elicited on the right ear. It might be thought that it has some connection with the greater Imp. on this ear. It is for all three frequencies at the border of the normal. There being as mentioned an intimate reflex co-operation between the muscles of the right and left ear, it might be presumed that the paresis of the left tensor tympani caused a disturbance of this co-operation with an increase of the state of contraction on the right side as a consequence. That may explain the increase of Imp. as well as the non-appearance of the muscle reflex.

Another patient (No. 54) with a bilateral perception affection has perhaps also a left paresis of the musculus tensor tympani, as is seen in the case report (p. 177).

Here too (at 512 and 768 Hz.) a considerably greater Abs. is found on the ear homolateral to the trigeminus paresis. (At 1145 Hz. there are quite different conditions, which cannot be explained. — Error?). The Phase is the same however.

At the reflectory muscle contraction a very considerable decrease of the Abs. (from 58 to 35 %) is obtained on the left ear (with the paresis). On the right ear only a just measurable reaction is obtained.

The same explanation as for the preceding patient may be used, only the muscle contraction on the right ear is smaller. In return the Imp. has changed exactly in the direction which would be expected.

This patient probably has a bilateral perception affection besides (the poor bone conduction).

Facial paralysis.

Only a couple of patients who suffered from unilateral facial paralysis have been examined. The examination of the ears showed nothing abnormal, possibly because there was no stapedius paralysis.

It certainly will be of great importance to continue these examinations of the muscle reflexes partly with regard to the physiology of the muscles, partly out of regard for the clinic.

It will probably be easy to determine the threshold of the muscle reflex for pure tones on normal ears with the aid of the acoustic bridge, as *Perlman* et alii have done on ears with perforation.

An examination of the ears on patients with trigeminus respectively tensor paresis and facial respectively stapedius paresis certainly may contribute to the future elucidation of the mode of action of the muscles, especially with regard to the tensor tympani which it has not been possible to examine in any other way.

In the otological clinic f. i. it will be possible to examine spastic conditions in the muscles which have been made

responsible for reductions of hearing (f. i. *Zöllner*, *Josephsen*, and others), but that has never been demonstrated directly. A tensor paresis, as described in the first case, can only be demonstrated in this way. The usual examinations afford no information whatsoever about it.

For the neurological clinic there is a possibility of examining a reflex arc which it has not previously been possible to examine.

The Impedance measuring and the intra-aural muscles.

As the Imp. measuring is performed with the help of a tone of a certain intensity, it is very important to find out whether it elicits a muscle contraction.

It will not beforehand be expected that a muscle contraction will be elicited, as the intensities which have been used are below the threshold mentioned, at any rate, for the stapedius reflex. The maximal intensity has approximately been 50—60 db. In sufficiently quiet surroundings the Imp. can be determined with quite weak tones.

Numerous measurements have been made on normal ears, first with the weakest possible tone, subsequently with stronger tones up to maximal intensity, without any difference being demonstrable. After the adjustment of the comparison resistance to equilibrium the tone intensity may be increased to a maximum without disturbance of the equilibrium. On the other hand it has been possible in some cases to demonstrate a very brief change if the tone after the adjustment was interrupted and suddenly put on maximal intensity again. The examiner then hears the tone for a moment, after which there is silence again as a sign of equilibrium. Probably, as is also described by *Lüscher* and others, the sudden onset of the relatively weak tone has caused a muscle contraction of short duration.

It has been tried to "fatigue" the reflex arc with a tone of maximal intensity for up to 10 minutes, and there has in some cases been found a doubtful change of the Abs. in the direction of greater Abs.

B. MEASURINGS ON DIFFERENT EARS — THE NORMAL MATERIAL

1. SELECTION OF SUBJECTS

The normal material for this orienting examination has been collected so that, at first, a number of patients with normal ears were examined, to whom there was easy access and who were suited for these — at first — protracted and repeated examinations with experiments bearing upon the connection of the apparatus to the ear and the different sources of error discussed, etc. There is a question of 13 patients with slight lung tuberculosis who were not confined to bed.

Later 9 perfectly healthy persons and 8 patients admitted to the otological ward of the Rigshospital for other reasons than ear diseases have been examined.

In none of the 30 cases were there or had there been any ear symptoms. The hearing was reported to be normal, and there was no familial hardness of hearing.

The ear drums in all cases were perfectly normal and the hearing for conversation voice and whisper was more than 12 m. In 13 cases an audiogram was made in a sound-proof room and was found normal.

In all the cases the cavum nasi and rhinopharynx were normal apart from one patient admitted to the ear ward who suffered from hypertrophic rhinitis.

At first we were satisfied with this preliminary normal material — chiefly consisting of tuberculosis patients — and then proceeded to examine patients with different ear affections, simultaneously supplementing the two last mentioned groups.

The intention was to get a pure normal material and a material of patients with normal ears, but with different diseases. This latter group should eventually be subdivided after affections, especially after affections of the upper air passages as a separate group.

This plan could not be carried through for certain reasons. The present material must therefore be used as far as it is possible to do so.

The relatively healthy tuberculosis patients certainly do not, as far as ears are concerned, differ from quite normal persons. There is considerably more reason to believe that this is the case with the last group of patients, especially those with diseases in the upper air passages even if there are no demonstrable objective symptoms.

There might therefore be reason to include in the normal material only the two first mentioned categories, especially as will be seen that some of those 8 patients actually differ from the main group, and single patients cannot be omitted. This will imply the advantage that there is a better separation between the normal and patients with conduction affections.

The hard-hearing persons who will have to be examined in practice will, however, often be patients with other complaints, especially the very frequent slight affection of the upper air passages. It will thus be necessary to take into consideration. how the Imp. behaves in such patients without ear symptoms. As it is not possible to present such a material for comparison, it seemed best to include those few examined patients with normal ears and thus let them influence the normal material proper.

A perfectly pure normal material probably is chiefly of theoretical interest. The change to which it is submitted by the adopted method can only be in the direction of a minor difference between the normal and patients with conduction affections.

Changes of the sound conduction apparatus due to diseases in the ear will very probably always be in the direction of a decrease of the conduction faculty. The only exception which may be thought of if the drums are normal are paretic conditions of the intra-aural muscles and, as was mentioned before, patent tuba but partly these exceptions are rare, and partly they can be diagnosed in another way.

A difference found between the normal material and ears with conduction affections thus will not be compromised by this method. On the other hand, an eventual difference between the normal and patients with perception affections will naturally be judged very cautiously.

Table 6. Normal ears. ($v^0 = -9^0$).

No. Sex Age (years)	Right ear								Left ear							
	384		512		768		1145		384		512		768		1145	
	a%	v^0	a%	v^0	a%	v^0	a%	v^0	a%	v^0	a%	v^0	a%	v^0	a%	v^0
1 M. 38.....	—		45	43	78	96	—		21	34	32	39	52	73	83	103
4 M. 13.....	36	44	52	45	57	79	72	100	30	34	45	39	57	64	76	88
6 M. 42.....	26	36	34	45	56	76	60	100	16	34	30	47	43	71	63	98
7 M. 44.....	28	51	36	65	80	120	90	104	29	45	42	57	63	110	>92	120
9 M. 22.....	17	35	31	45	48	78	70	88	20	30	42	37	55	74	88	73
15 W. 37.....	11	19	18	33	23	42	51	51	12	21	20	27	25	40	48	50
16 W. 37.....	14	28	28	33	42	54	62	79	18	32	25	43	48	64	70	82
17 M. 23.....	—		—		—		—		24	23	43	31	54	50	72	69
18 W. 21.....	—		—		—		—		30	29	40	32	72	74	—	
23 W. 24.....	38	36	55	45	83	104	85	73	41	39	55	51	0 Min		71	73
24 W. 20.....	—		—		—		—		39	30	49	37	70	76	88	112
25 M. 31.....	21	35	28	40	55	71	67	78	24	34	34	39	63	72	78	76
27 M. 25.....	31	25	47	26	62	50	75	52	—		40	26	—		—	
31 M. 28.....	23	31	31	34	48	60	66	84	18	34	31	34	45	63	70	91
35 W. 22.....	26	29	37	32	55	62	69	66	25	32	36	38	58	64	70	79
39 W. 24.....	—		36	41	63	76	63	73	—		40	34	54	60	61	78
40 W. 20.....	—		25	32	31	52	—		—		22	32	34	48	—	
43 M. 33.....	—		29	30	45	51	56	67	—		23	28	34	46	45	58
44 M. 19.....	—		20	34	36	54	55	71	—		22	34	43	51	53	73
47 W. 20.....	—		3	32	15	36	23	42	—		10	29	24	38	56	50
56 W. 16.....	—		36	30	49	54	75	62	—		39	37	54	60	76	76
61 M. 15.....	20	37	34	40	57	70	81	82	13	36	22	40	30	56	76	80
72 M. 38.....	35	33	60	41	81	74	76	76	28	34	41	37	73	83	75	68
76 W. 26.....	29	19	35	17	43	36	72	56	28	15	37	12	43	32	57	41
85 W. 14.....	12	27	16	32	47	55	72	48	9	25	15	29	31	45	55	58
87 W. 31.....	30	22	43	25	63	47	69	53	29	20	34	20	54	40	61	52
92 M. 56.....	—		17	34	31	54	59	78	—		10	34	17	48	24	64
93 W. 20.....	27	24	40	26	70	67	90	76	23	27	37	25	68	53	75	45
96 W. 27.....	23	29	36	31	57	59	0 Min		22	30	34	36	59	71	0 Min	
101 M. 43.....	10	28	22	28	38	42	30	44	18	26	29	28	41	42	36	51

Diagnosis:

Nos. 1 to 27 incl.: Tuberculosis pulm. or obs. for Tub. pulm.
No. 35 Tonsillitis acuta recidivans.
- 44 Cephalalgia.
- 47 Paresis musc. arytaenoidei transv.
- 56 Tonsillitis ac. recid.

No. 85	Angina recidivans — Veg. adenoid. levi gr.
- 92	Cancer laryngis.
- 93	Rhinitis chronica.
- 96	Tonsillitis chron.
The rest:	Normal.

On the 30 persons not all the ears have been examined at the different frequencies, as seen in the table below.

In Table 6 are recorded number of patient, sex, age, diagnosis, and the values of the Abs. and Phase for the 4 frequencies used. As patient No. here — as in the material of hard of hearing — the original numbers were retained which indicate the succession in which the patients were examined. It is of a certain interest with regard to the certainty of the measuring which gradually increases with increasing technical skill. The single figures are the mean values of several measurements.

Always at least 3 measurements were made, in most cases many more; frequently they were repeated on different days. A few results which turned out to be quite different from the others, were quite obviously due to one source of error or other and were omitted.

In Table 7 are recorded the mean value, the standard deviation, and the number of ears examined at each frequency for the Abs. as well as for the Phase.

Table 7. The mean value of the Imp. components for the normal material.

	$\bar{X}_a$ %	s	$-\bar{X}_\varphi^\circ$	s	$\bar{w}$	$-\bar{q}$	u	n
384	24	± 8	30	± 8	97	349	7.4	41
512	33	±12	35	± 9	100	286	10.9	57
768	51	±17	62	±18	62	149	23.8	55
1145	66	±16	72	±19	68	114	38.6	50

2. THE MAGNITUDE OF THE IMPEDANCE — COMPARISON WITH PREVIOUS INVESTIGATIONS

In Fig. 12 and Fig. 13 the results are shown in the complex plane for the frequencies 512 and 768 Hz., in Fig. 14, for 384 and 1145 Hz. The values for the 4 frequencies are in 4 groups which fuse however.

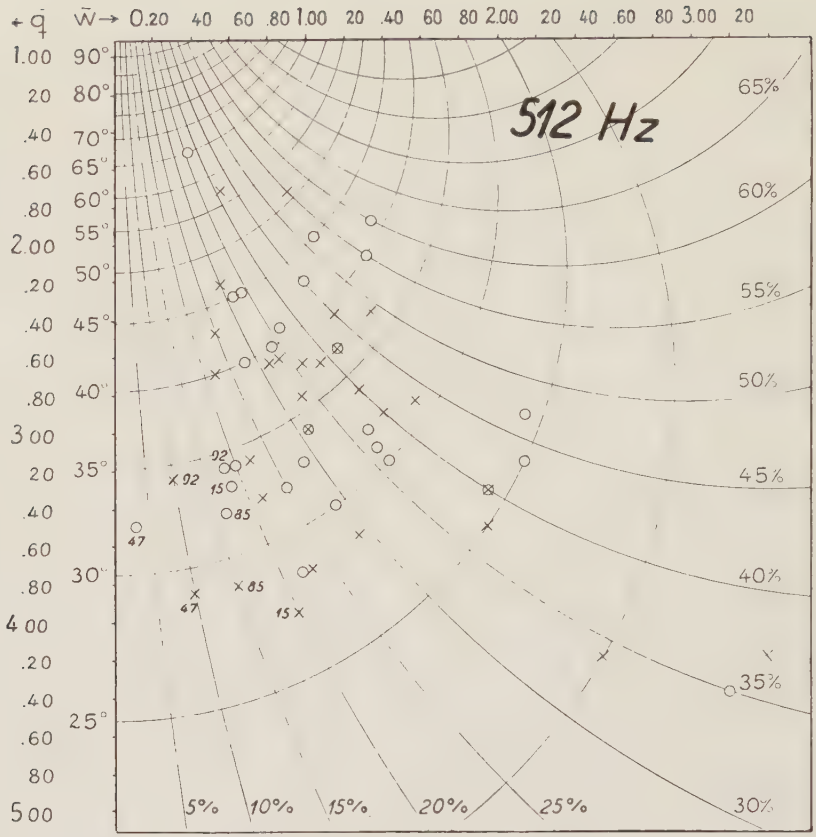


Fig. 12. Normal ears. 512 Hz.
(o right ear, x left ear).

At 384 Hz. the reactance is negative, i. e. elastic and great. For the following frequencies it decreases and is lowest at 1145 Hz., but remains negative for all the examined ears. $\bar{w}$ — the resistance component — is about 1.00 at the two lowest frequencies and is somewhat lower at the 2 highest, but at the same time $\bar{q}$ is reduced so much that u becomes greater.

How do these components of the value of the impedance agree with the values recorded in the literature?

A direct comparison with the measurings of *West* is, as mentioned, not possible, because *West* performs the measur-

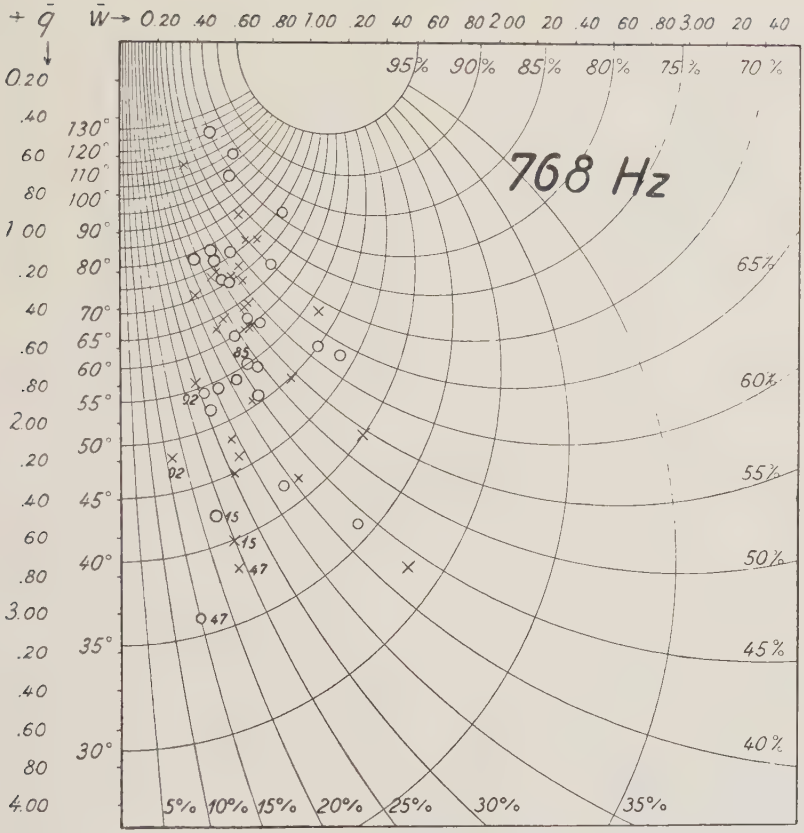


Fig. 13. Normal ears. 768 Hz.
(o right ear, x left ear).

ings in another place. This is without doubt also why he in some cases finds the reactance positive at 500 Hz.

The decreasing value of the reactance in the range of frequency here examined corresponds to the course of *Tröger*'s and *Geffcken*'s Imp. curves. To be able to compare the magnitude of the components they must first be converted so that they have the same unit, next being reduced to the same place in the meatus. The conversion of *Tröger*'s and *Geffcken*'s measurings is recorded on page 61, so that they, just as the writer's own measurings, have the wave resistance of the air as a unit, but they refer to the conditions at the drum.

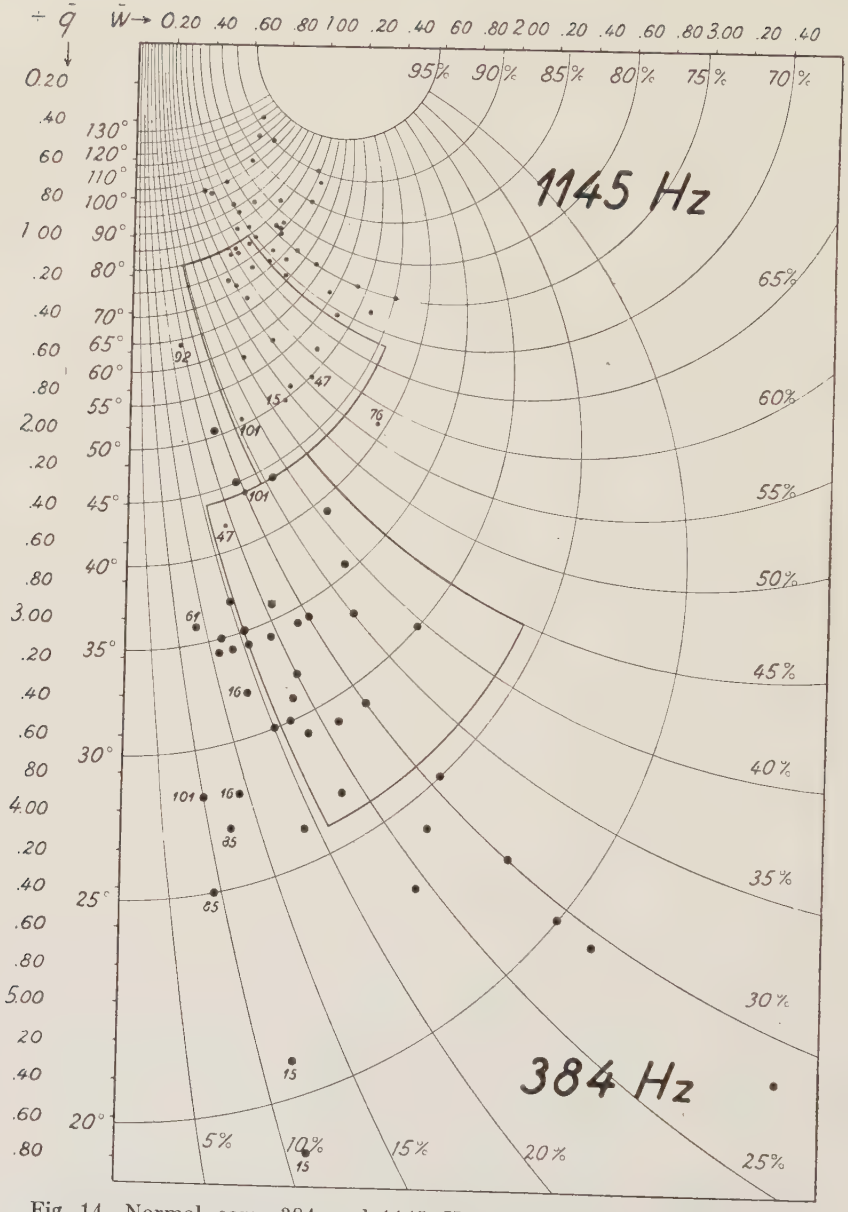


Fig. 14. Normal ears. 384 and 1145 Hz. Noted are the mean dispersion areas for 512 and 768 Hz. (· 1145 Hz. • 384 Hz.).

The mean values found here were therefore converted to the drum according to the following formulae.

$$1 - a_D = (1 - a_M) \cdot e^{4\beta L} \qquad \vartheta_D = \vartheta_M + 2\,\alpha\, L,$$

where a_M and ϑ_M are the values in the "measuring plane" a_D and ϑ_D at the drum. L is the distance between the measuring plane and the drum which averagely is 1.6 cm. (p. 78).

The change in the Abs. thus becomes so small that it is negligible. (At 1145 Hz. where it is greatest, $e^{4\beta L} = 1.043$).

The mean value of the Phase corrected to the drum becomes:

384 Hz. — 17°, 512 Hz. — 18°, 768 Hz. — 36°, 1145 Hz. — 33°
- 24% - 33% - 51% - 66%

The components $\bar{w} \cdot 100$ and $\bar{q} \cdot 100$ corrected to the drum:

384 Hz. $\bar{w} = 270$	512 Hz. $\bar{w} = 298$	768 Hz. $\bar{w} = 143$
$-\bar{q} = 556$	$-\bar{q} = 448$	$-\bar{q} = 231$
	1145 Hz. $\bar{w} = 182$	
	$-\bar{q} = 176$	

Both $\bar{w}$ and $\bar{q}$ in *Tröger*'s example are rather smaller for frequencies in the neighbourhood of the 3 lowest frequencies used here so that the Imp. has come nearer to the zero point of coordinates. In the range 700—860 Hz. the Imp. has become so small that it practically corresponds to the wave resistance in air, i. e., $u = 1$. Such a position was at 768 Hz. found in a few ears, but in most cases the Imp. is much greater. The same applies to 384 and 512 Hz. At 1145 Hz. $\bar{w}$ is greater than at the ears examined here.

The values for *Geffcken*'s test person are on the other hand very near to the mentioned mean figures. Only at 800 Hz. is a moderate deviation in the opposite direction of that found by *Tröger*. *Geffcken* thus finds the Imp. fairly great just in that range, where *Tröger* found a minimum.

Waetzmann and *Keibs*' $\bar{w}$-values are somewhat smaller, whereas $\bar{q}$ approximately corresponds to the mean figures. However, at 768 Hz., also the $\bar{w}$-values are very close to each other. The same applies to measurings at the 2 frequencies which have been reported by *Keibs*.

The values of *Kurtz*'s measurings on 2 normally hearing

persons for the one person are very low (small Abs., small Phase) for the lower frequencies, especially for the one ear where the values corresponding to 512 and 700 Hz. are outside the mean dispersion area of the normal ears measured here. The values for the other persons are high (high Abs., great Phase) at 768 Hz., however, within the mean spreading area.

Waetzmann and *Menzel* who have used the acoustic bridge report Abs.-curves for 6 normal persons. The Phase is not stated. All the values corresponding to the 4 frequencies used here are — approximately judged according to the curves — within the mean spreading area of the frequencies concerned.

Summarily it may be said that there is good agreement between the magnitude of the Imp. components — previously found with other methods and with the acoustic bridge — and the measurings performed here on normally hearing ears. The examples recorded in the literature present fairly great individual differences but the course and dependence of the Imp. curve upon the frequency at the lower frequencies are the same in all cases.

In the following only Abs. and Phase will chiefly be discussed. When there is a question of clinical examinations it is just as well at once to attribute the changes found to these two directly measured magnitudes. The more physically interested reader will always be able from them to calculate the magnitude of the Imp. itself and its two other components.

3. DISPERSION OF MEASUREMENTS

Glancing at the Figs. 12—14 the considerable dispersion of the values is immediately noticed, and it appears too from the standard deviation registered in Table 7. It is considerably greater than the spreading at the serial measurings on the same ear, which at 512 Hz. is 2.6% and 1.6°. The great dispersion thus cannot be explained by the measuring errors but must be caused by differences between the examined ears.

How great a part of the dispersion is possibly to be explained alone on the ground of the importance of the part of the meatus lying between the measuring plane and the drum mentioned in

Chapter 6, and how great a part may be attributed to individual differences of the sound conduction apparatus? The question can only be answered in the way that an examination is made as to what influence differences in the meatus may be expected to have, and per exclusionem assume that the remaining difference must be due to causes in or medially to the drum. What influence the meatus has, is also difficult to say because — as mentioned before — several partly concurrent factors, partly factors counteracting each other, assert themselves. To be able to answer that, it will be above all necessary to know the dimensions of the meatus and the distance from the measuring plane to the drum of all the examined persons. The distance from the measuring plane to the ear drum is easy to measure — as was previously described — but in order to do this the drum must be touched with a probe. In order not to compromise the Imp. measuring this can only be done afterwards and then it is not sure that the distance is exactly the same as it has been at the measuring. A change of a few mm. can easily occur through slight movements of the head. For such an examination exact fixation of the head is required. Furthermore it is difficult to get the exact measure of the width of the meatus.

The experiments which were made in order to measure the distance to the ear drum and approximately determine the width not affording any valuable information they were given up.

The question thus cannot be fully solved but one must be satisfied with the information to be obtained by parallelling the dispersion with the examinations made in Chapter 6.

The Phase. Differences in the length of the meatus give pure differences of Phase. To a maximal difference of the distance from the olive to the ear drum of 14 mm. (p. 90) + a maximal increase of the distance to the drum of about further 6 mm. — an account of inaccuracy of insertion of the olive or displacement of it, so that it is not so far inside as possible during the measuring itself — corresponds a maximal difference of Phase of 16, 22, 33 and 48° for the frequencies 384, 512, 768 and 1145 Hz.

That corresponds approximately to the difference between

the limits of the mean deviation. Some of the ears thus have a still greater Phase difference. It being thought, moreover, that the maximal difference in distances measured here only exceptionally has existed at the measurings, for one thing, because patients with very narrow ear canals were omitted, it is probable that at any rate the great differences of Phase are due to individual differences in the sound conduction apparatus itself. How great a part of them or if the moderate and small differences of Phase have one cause or another, is impossible to determine after these examinations.

Differences of width of the auditory canals also cause differences of the Phase, namely, a numerically higher Phase thus being obtained on ears with large canals, and inversely a smaller Phase on narrow canals. The dispersion, for this reason, however, can only be small and will be counteracted by the olive which in case of wider meatus often can be inserted farther.

The Absorption. Presuming that the meatus is not very narrow and that the olive has been pushed in as far as to the bony meatus, by which the previously mentioned sources of error are eliminated, there should only be a possibility of very small variations of Abs. In those cases where the olive only can be pushed a short way into the cartilagenous meatus, there is, of course, (as mentioned before) the possibility of an increase of Abs. Partly there has only been a question of a few ear canals, partly it was ascertained not to be the case by control with a smaller olive (cf p. 88).

It must therefore be assumed that the dispersion of the Abs. values, besides what is due to the measuring errors, mainly are due to differences in the sound conduction apparatus.

Of the greatest importance with regard to the later examination of sound conduction affections is the dispersion of the Abs. downwards towards the lower values. In Figs. 12—14 the ears with the smallest Abs. are marked with numbers.

At 512 Hz. there is a question of both ears on the following persons:

Nos. 15, 47, 85 and 92. It is remarkable that they are not single ears of different, but both right and left ear of the same,

persons. 3 of them (Nos. 47, 85 and 92) are patients who had been admitted to the ear ward for other complaints than ear disease.

No. 47 is a woman, 20 years of age, admitted because of hoarseness. Besides a transversus paresis the examination did not disclose anything abnormal.

No. 85 is a child, 14 years of age, admitted because of tonsillitis recidivans. There was very little adenoid tissue in the rhinopharynx.

No. 92 is a cachectic man, 56 years of age, with cancer laryngis. As mentioned, none of these patients had ear symptoms and the audiograms were fully normal.

No. 15 was a woman 37 years of age with lung tuberculosis The hearing had only been examined with whisper and conversation voice.

At 768 Hz. the values with the lowest Abs. correspond to the same patients, only the Abs. for No. 85 at this frequency is rather high (31 and 47 %).

Apart from these — with regard to the normal — somewhat problematic patients the Abs. is for all the other ears examined at 512 Hz. $\geqq 20\,\%$, at 768 Hz. $> 30\,\%$. Also the Phase in the ears in question presents deviations, as it is smaller than the average, especially at 768 Hz.

Of the mentioned patients only Nos. 15 and 85 were examined with 384 Hz. The Abs. is also here low for both right and left ear. No. 15 has at this frequency a remarkably small Phase (-19 and $-21°$). 3 other ears are also below 15 % (16, 61 and 101).

With 1145 Hz. No. 15 has a relatively small Abs. The right ear of No. 47 and the left ear of No. 92, which were the lowest values found at 512 and 768 Hz., have also at 1145 Hz. a very low Abs. (23 and 24 %).

At this frequency only the measuring results for right and left ear of 1 patient (No. 101) are below 50 % — uncertain for what reason.

A valuation of the results in this way gives a picture differing somewhat from that derived from an estimation according to the mean value and dispersion. It is seen that the extreme

values with the lowest Abs. and smallest Phase correspond to the ears of patients who also in another way differ from the average. It is possible that these ears in reality are pathological and have an impairment of conduction which only does not give other symptoms, but what is sure and significant is, that such a low Abs. may be found without clinically demonstrable hearing loss. In order to pay regard to this fact the total material was used, as accounted for above. Its mean value and standard deviation for the 4 frequencies is noted in all the diagrams below for comparison with the deafened ears. The lowermost limit of the standard deviation indeed corresponds fairly well to the figures mentioned here: 20, 30 and 50 % for the frequencies 512, 768 and 1145 Hz., which probably are the proximately lowermost limits if the material is pure.

The dispersion upwards towards the high Abs. is evident from the diagrams. It is of minor interest, mostly on judging the influence of eventual sources of error on the measuring result (especially leakages at the connection).

The dispersion due to differences in the measured Phase is also evident from Figs. 12—14 and from the mean dispersion areas drawn as well as from Table 7. This is discussed in the next chapter.

A comparison between the Imp. of the right and left ear is of considerable interest, firstly in order to find out whether there is any difference between the mean values of Abs. and Phase for right ears and left ears, secondly to compare the average and maximal difference with the sources of error.

The difference between the mean figures was calculated as:

$$\frac{2\,\Sigma(\overline{X}_R - \overline{X}_L)}{n}$$

and the average difference (right-left dispersion (S_{RL}) as:

$$\sqrt{\frac{(\overline{X}_R - \overline{X}_L)^2}{n}};\ n = \text{number of ears.}$$

The difference between the mean figures for right and left ear (Table 8) is very small — also at 768 Hz. where it is

greatest — in proportion to the dispersion, nor is it real. It certainly is fortuitous that the difference is positive at all frequencies (but it agrees with the fact that *Lucae* found a great Abs. on the right ear).

The average difference between right and left ear is expressed in the right-left dispersion which, just as the maximal difference is recorded in Table 8. The bracketed figures indicate single isolated measuring results deviating from the others.

As it may be assumed that the auditory canals of the same person in most cases are equal, this difference must be due to the technical defect at the measuring (i. e. chiefly to the deficient connection to the meatus) and eventual differences in the Imp. of the ears. In this way the influence of the meatus has been eliminated to a certain degree.

How great a part of the difference found may be attributed to the measuring errors and how great a part can be reckoned as being caused by differences of Imp.?

The Absorption. For the previously mentioned reasons the difference of the Abs. presumably for the greatest part must be due to differences in the Imp. of the right and left ear.

The Phase. In chapter V was mentioned the difference of distance between "measuring plane" and drum of the right and left ear of 50 persons chosen at random, by the introduction of a 7 mm. tube. Mostly it amounts to 0—3 mm., in isolated cases up to 5 mm. The difference of Phase ($2\,a\,L$) at a change of distance (L) of respectively 3 and 5 mm. is recorded in Table 8.

The mean difference of Phase found (the right-left spreading) exactly corresponds to the change of Phase at a difference of distance of 3 mm., which is the approximate mean difference of the measured distance from the ear drum.

The maximal difference of Phase between right and left ear is on the other hand greater than the greatest measured difference of the distance from the drum.

Thus, as regards the Phase, the difference can be explained by the measuring errors alone.

That the difference in some persons is greater than would be anticipated after the distance measurings, may be due to

the circumstance that it has not been possible to place the olive so exactly or keep it so precisely in its place during the Imp. measuring as during the distance measurings which require but little time and were performed solely for this reason. It is, of course, not excluded that a difference of Imp. in these case may have influenced the Phase, but in most of the cases the difference of the Phase corresponds to that inevitable small difference in the distance from the drum.

Table 8.

TheABSORPTION	384	512	768	1145
Difference between the mean values $(\bar{X}_R - \bar{X}_L)$	+ 1.3%	+ 1.7%	+ 4.0%	+ 1.6%
The R. — L. — dispersion	3.3%	5.0%	7.8%	9.4%
The maximal difference of Abs. between R. and L. ear	8 (10)	12 (19)	17 (27)	18 (35)
The PHASE				
Difference between the mean values	+ 0.8°	+ 1.0°	+ 3.9°	+ 1.2°
The R. — L. — dispersion	2.6	3.3	6.6	7.8
The maximal difference of the Phase between R. and L. ear	6 (10)	8 (10)	16 (23)	16 (31)
Calculated difference of Phase after an *average* distance difference of 3 *mm*	2.4	3.2	4.9	7.2
Calculated difference of Phase after a *maximal* distance difference of 5 mm	4.1	5.4	8.2	12.1
Number of persons	18	27	25	23

5. THE REFLECTORIC CONTRACTION OF THE INTRA-AURAL MUSCLES (MR)

The muscle reflex (MR) was examined on 20 persons of the normal material (Nos. 24 to 101 incl.). The technique of the examinations is described in Chapter VI.

On these 20 persons were examined 37 ears. 3 ears were not examined.

The muscle reflex was found to be positive on 31 ears, dubious on 1 ear, and negative on 5 ears. Four out of the 6 ears with negative or dubious reaction were those of three persons (No. 47 R. and L., No. 85 R. and 92 L.), who were mentioned under Imp. measuring, and whose ears had a

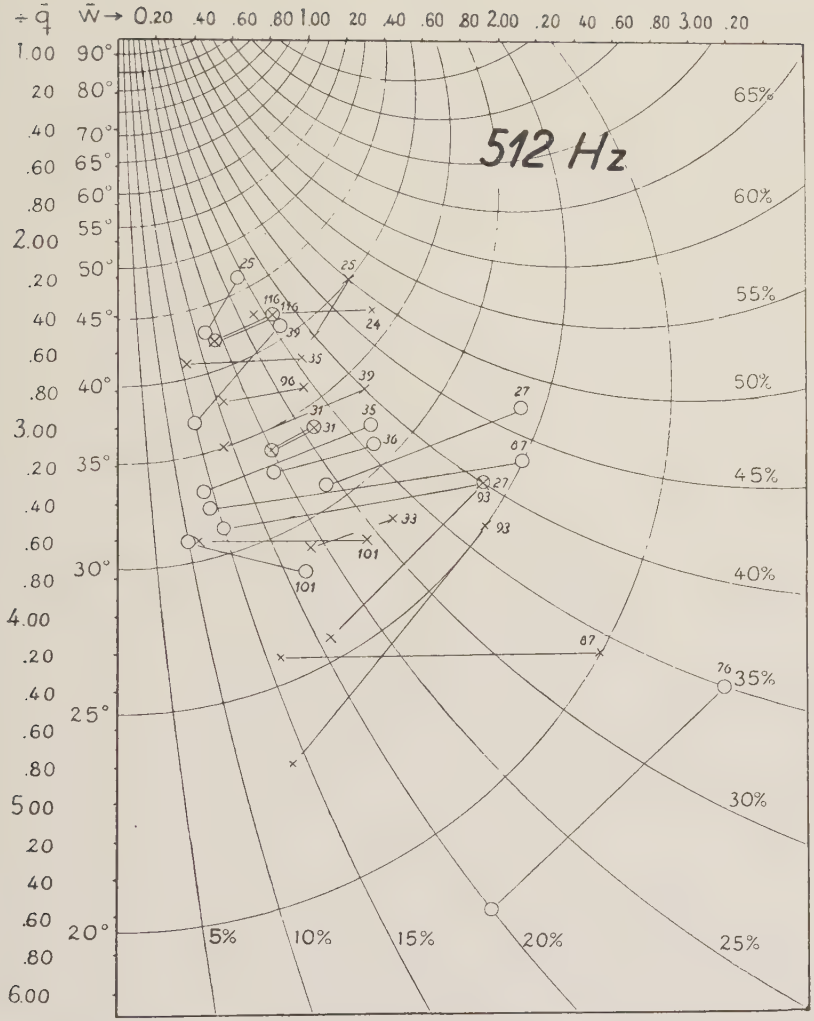


Fig. 15. The change of impedance at the acoustic reflex contraction of the intra-aural muscles.

small Abs. The last 2 ears with negative reaction were of the same person, No. 40 who does not differ from the other persons of the normal material.

With the exception of one person, thus it is the ears of the same persons as have a particularly low Abs. that also present

the deviations with regard to the muscle reflex. Fig. 15 shows the change of Imp. on those ears, where it was measured at 512 Hz. The determination of Imp. during the muscle contraction being only approximate, it seems not to be of any further interest to quote the very figures for the measurings. The change of Imp. is moreover discussed in Chapter VI.

VII. THE IMPEDANCE IN DEFINITE CONDUCTION AFFECTIONS ASSOCIATED WITH PATHOLOGICAL CHANGES IN THE EAR DRUM

After having examined the Imp. of the normal ear the first important task is to solve the question, if the conduction affections give rise to definite changes of Imp. demonstrable with this method and, if so, what changes.

At first were selected ears with affections of the middle ear and changes of the ear drum on account of inflammations or sequelae of such. Usually no audiometric determination of the degree of the impairment of hearing was made, but all the ears had considerable losses of hearing.

A. UNILATERAL CONDUCTION AFFECTIONS WITH CHANGES IN THE EAR DRUM DUE TO INFLAMMATIONS OR SEQUELAE OF SUCH

In Table 9 are recorded Abs. and Phase both for 10 ears with such affections and for the contralateral normal ears. The results are quoted for the 4 frequencies used, and the single values are, as usual, mean values for several measurings.

In Fig. 16 are traced Abs. and Phase curves respectively. In both cases the frequencies are plotted on the axis of abscissas, the Abs. or Phase on the ordinate.

The absorption curves for all the frequencies show a very marked difference between the pathological ears and the nor-

mal contralateral ears. In 8 patients the two groups of curves are entirely separated: much lower for the pathological ears than for the normal ears. The Abs. of 2 pathological ears (No. 14 right and No. 20 left) are, however, relatively high.

The Phase curves do not show any sure difference between normal and pathological ears. The dispersion is smaller than

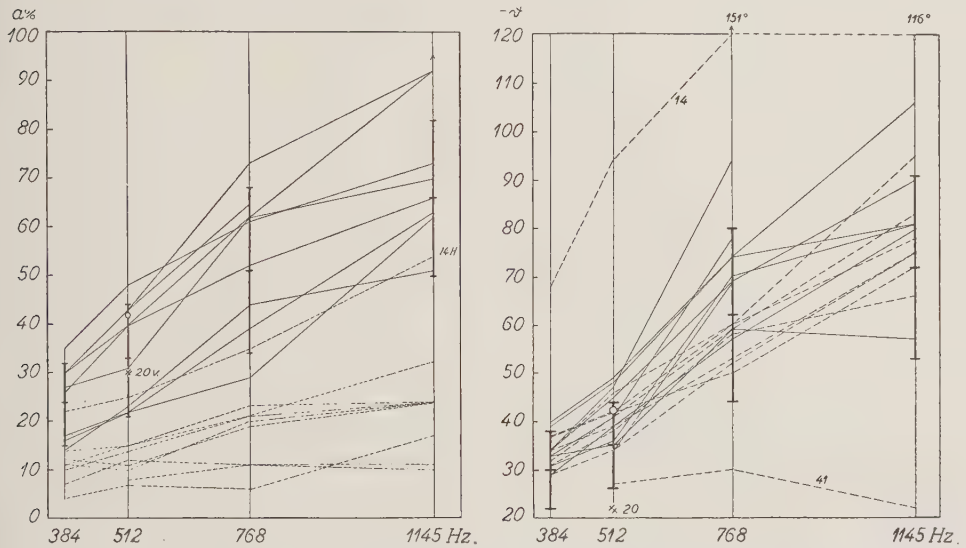


Fig. 16. Abs. and Phase curves for unilateral conduction affections on account of inflammations or sequelae of such, and curves for the opposite normal ears.

——— normal ears. -------- pathological ears.

for the Abs. curves. Only 3 Phase curves deviate clearly from the Phase curves for the opposite ear. Corresponding to the one (No. 41 right) is a very low Abs., that is, an ear with a conduction affection which, besides reducing the Abs., has changed the Phase considerably in relation to the contralateral normal ear.

The two other ears are also of great interest. On one of the ears (No. 20 left) the measurements were made for one frequency only: 512 Hz. The Phase is numerically considerably smaller than for the opposite normal ear. On the other ear (No. 14 right) the Phase for all the 4 frequencies is numerically

Table 9. Unilateral conduction affections with changes in the ear drum on account of inflammation or sequelae of such. ($v° = -\vartheta°$).

No.	Sex Age	Diagnosis	Ear	384		512		768		1145	
				a%	$v°$	a%	$v°$	a%	$v°$	a%	$v°$
2	M. 23	Otitis med. sin. tuberculosa? A. sin. Dry, drum slightly swollen, yellowish, no perf. $v.$ > 12.00/0,10	R.	26	34	40	45	52	69	66	90
			L.	11	34	15	39	23	53	24	75
5	M. 36	Otitis med. supp. chr. sin. seq. A. sin.: Dry, large central perforation. $v.$ > 12.00/aa	R.	35	39	48	48	61	74	73	81
			L.	14	37	15	42	21	60	32	95
10	W. 35	Otitis catarrh. dxt. A. dxt.: Drum dull, strongly retracted. $v.$ 0.10/> 12.00	R.	7	31	12	38	11	58	11	66
			L.	17	40	22	49	39	74	63	106
12	M. 30	Otitis med. supp. chr. sin. A. sin. Dry, the most of pars tensa is missing. $v.$ > 12.00/0.20	R.	16	29	22	39	29	57	62	80
			L.	11	32	10	41	20	59	24	83
13	M. 35	Otitis med. supp. chr. sin. seq. A. sin. Almost total defect of pars tensa. $v.$ > 12.00/aa	R.	30	34	43	47	73	94	0	Min.
			L.	12	34	11	46	19	60	24	78

considerably higher than on the normal ear; for 1145 Hz. it is even numerically $>-180°$. On comparison with the Abs. curves these two ears prove to be the very two pathological ears with relatively high Abs. The Abs. measuring thus merely shows that the two pathological ears have a slightly lower Abs. than the contralateral normal ears; it is within the area of the normal ears, and the difference is not greater than is often found in perfectly normal ears. The great difference in the Phase is not normal, however. Only the full determination

Table 9 continued.

No. Sex Age	Diagnosis	Ear	384		512		768		1145	
			a%	*v*°	*a*%	*v*°	*a*%	*v*°	*a*%	*v*°
14 W. 25	Otitis med. supp. chr. dxt. seq. A. dxt. Dry. Small perf. posteriorly	R.	22	68	25	94	35	151	54	+116
	v. 0.20/>12.00	L.	27	33	31	41	62	78	0	Min.
20 W. 38	Otitis catarrh. ac. sin. A. sin. Drum red, strongly retracted	R.			42	43				
	v. >7.00/0.20	L.			30	22				
22 W. 21	Otitis med. supp. chr. dxt. tub. A. dxt. Large perforation anteriorly, strongly retracted cicatrix posteriorly	R.	10	29	14	34	21	52	24	75
	v. aa/>5.00	L.	30	31	40	36	62	70	70	81
41 W. 32	Otitis ac. dxt. A. dxt. Drum red, swollen.	R.			8	27	11	30	10	22
	v. aa/>6.00	L.			43	34	65	69		
78 W. 68	Otitis chr. sin. seq. A. sin. Drum retracted. Defect in pars flaccida.	R.	14	33	23	35	44	59	51	57
	v. > 3.00/0.10	L.	4	37	7	42	6	50	17	72

of the Imp. in testing these ears thus reveals that they are pathological.

The Abs. + Phase determination, i. e. the Imp. measuring, has in all cases disclosed sure relative difference between the normal and the opposite pathological ear. In regard to most of the pathological ears there were obtained absolutely pathological values besides.

The physical importance of changes of impedance in conduction affections. The magnitude of the components of the Imp. $\bar{w}$

Table 10. Unilateral conduction affections on account of inflammations or sequelae of such. $\bar{w}$, $\bar{q}$, and u at 512 Hz.

Normal ears.						Ears with conduction affections.				
No.	a%	v°	$\bar{w}$	$-\bar{q}$	u	a%	v°	$\bar{w}$	$-\bar{q}$	u
2	40	45	79	218	15	15	39	36	280	4
5	48	48	87	193	19	15	42	31	258	5
10	22	49	38	215	8	12	38	30	288	4
12	22	39	55	272	7	10	41	23	278	3
13	43	47	80	205	16	11	46	21	236	4
14	31	41	72	251	10	25	94	14	92	15
20	42	43	90	224	15	30	22	202	422	9
22	40	36	116	264	14	14	34	44	323	4
41	43	34	136	266	15	8	27	32	414	2
78	23	35	70	303	7	7	42	15	261	2

Table 11. Mean value and standard deviation of the absorption for 10 ears with conduction affections on account of inflammations and sequelae of such, and for the contralateral normal ear.

	Normal ears		pathological ears				
	$\bar{X}_a$	s	$\bar{X}_a$	s	t	f	t equivalent to 1%-level
384	24	± 8%	11	± 5%	3.9	14	3.0
512	35	±10%	15	± 7%	5.3	18	2.9
768	54	±15%	19	± 8%	6.1	16	2.9
1145	73	±15%	24	±13%	7.3	16	2.9

and $\bar{q}$ as well as u appears from Table 10, where they are shown for 512 Hz. The change of the numerical value and Phase of the Imp. appears from Fig. 17 where the Imp. is recorded in the complex plane, also for 512 Hz.

It is seen that, in most cases, a considerable decrease of the real component ($\bar{w}$) of the Imp. has appeared, and only a slight change of the imaginary component ($\bar{q}$), mostly an increase, at times a decrease. Only in one case there is an increase of $\bar{w}$ (No. 20 left ear).

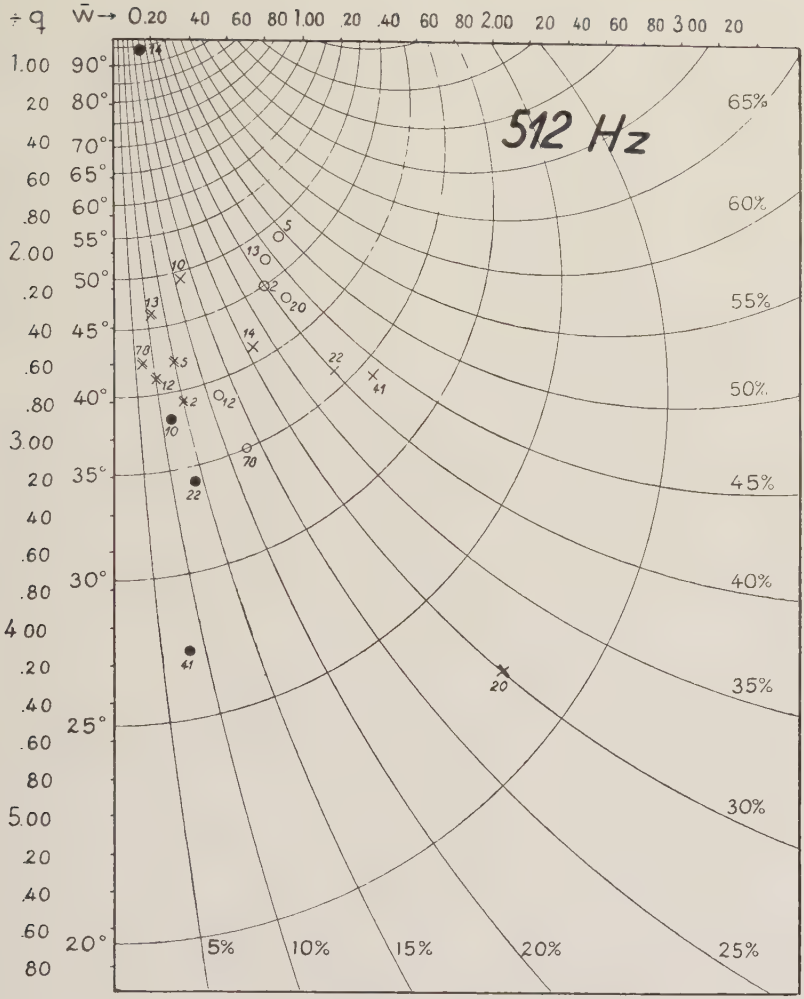


Fig. 17. The impedance for 10 ears with conduction affections on account of inflammations or sequelae of such and the contralateral normal ears plotted in the complex plane.

(Cross and circle: normal ears — double dagger and dot: pathological ears.

The numerical value of the Imp. is in most cases slightly increased, corresponding to an increase of $\bar{q}$. Its phase is in all cases changed in the direction of a higher numerical value.

In all cases with intact drum and in some cases with per-

foration u has become smaller. Only in one case — an ear with a dry perforation (14 right) has it become greater (even if the absorption has decreased).

That the real component of the Imp., the resistance $\bar{w}$., which beforehand is small, becomes smaller, means that the Imp. is on the way to becoming a pure reactance. The Phase being $> 180°$ and $\bar{q}$ thus being negative, the resistance is mainly due to the stiffness (or elasticity) of the sound conduction apparatus.

In the single case, where $\bar{w}$ has become greater (20 left), there has at the same time occurred such a considerable increase of $\bar{q}$ that u nevertheless has become smaller. The only case where u has become greater is No. 14, right ear. Here $\bar{w}$ has certainly become smaller, but $\bar{q}$ has at the same time decreased so much that u has become greater.

The numerical value of the Imp. has become very small (for 512 and 767 Hz.). At 1145 Hz. $\bar{q}$ has become positive, i. e. the mass of the system is now predominant.

The pathologico-anatomical changes which, in these conduction affections, give rise to the change of Imp., are of different nature. Common to them is a more or less pronounced fixation of the drum and the ossicle chain, which according to the above has caused an increase of stiffness of the system.

On the basis of these 10 ears examined it is difficult to say anything about the pathologico-anatomical changes underlying the differences in the change of Imp.

Only the 3 pathological ears which differ from the remaining 7 (see Fig. 17, the diagram of the Imp.) shall be discussed.

1. The only ear (14 right) where u — contrary to expectation — has become greater, had a small dry central perforation posteriorly in the drum. Such a perforation can wholly change the acoustic conditions and thus the reflection, which Lucae already has called attention to. The preliminary condition for the high Abs. must be an actually patent perforation. If the middle ear is filled with pus, a lower Abs. will naturally be obtained, but also a dry and apparently patent perforation may give a low Abs.

2. No. 20 left, was an ear with acute catarrhal otitis. The

drum was red, very strongly retracted. The Phase was very small. No explanation can be given for the relatively high Abs. It is not quite out of the question that one of the previously described sources of error may be the cause on account of the somewhat imperfect technique in the beginning.

3. No. 41, right ear, with a low Abs. and a small Phase was the seat of subsided acute otitis. The discharge had ceased, but the ear drum was still red and swollen, and there was a loss of hearing of about 40 db. for the frequencies used during the Imp. measuring. The small difference of phase is — as will be seen in the following — often met with in conduction affections and is, in combination with the low Abs., a consequence of the increased stiffness.

B. FURTHER EXAMINATIONS OF CONDUCTION AFFECTIONS WITH CHANGES IN THE EAR DRUM ON ACCOUNT OF INFLAMMATIONS OR SEQUELAE OF SUCH

In order to further examine the changes of Imp. on ears with conduction affections and changes of the ear drum due to inflammations or sequelae of such, some patients with bilateral conduction affections of this kind were submitted to examination.

In Table 12 are recorded the diagnosis, the features of the drum, loss of hearing as well as Abs. and Phase for these ears. In this table also are registered 4 patients whose hearing on one ear was normal, but who presented unmistakable changes of the ear drum. These ears are thus normal as regards function, but pathological on account of the changes of the drum. They are not included in the diagrams but they will be described in some detail later. There is further shown one ear (with conduction affection) of a patient with a perception disease on the other ear.

Just as for the unilateral conduction affections the Abs. and Phase curves are shown in Fig. 18.

The Abs. curves are seen to be low (No. 8 left, and 88 right), or very low — at all the frequencies — for all the ears with

Table 12. Bilateral conduction affections with changes in the ear drum due to inflammations or sequelae of such and single ears with such changes of the drum but with normal hearing ($v° = - \vartheta°$).

No.	Sex Age	Diagnosis etc.	Ear	384		512		768		1145		Loss of hearing in db.	
				a%	v°	a%	v°	a%	v°	a%	v°	512	1024
8	M. 40	Otitis med. supp. chr. d. + s. seq.	R.	16	30	21	41	45	59	83	107		
		A. dxt. + sin. Large cic. v: >16.00/0,20	L.	12	34	17	45	24	62	40	80		
26	M. 40	Otitis med. supp. chr. s.	R.			6	33	16	43	28	50		
		Otitis med. supp. d. seq.											
		A. dxt. Dry. drum cic. Perf. in membr. fl.											
		A. sin. Some pus. Perf. in membr. flaccida											
		v: 3.00/2.00	L.			12	34	14	44	28	48		
45	W. 48	Otit. med. supp. chr. d.	R.			5	33	9	42	23	48	60	50
		Otit. med. supp. chr. s. seq.											
		A. dxt. Large, marginal defect. Cholesteatoma.											
		A. sin. Retracted cic. in pars flaccida	L.			16	37	35	61	70	74	5	0
51	W.44	Otit. med. supp. chr. d. + s. seq.	R.			31	55	45	89	58	144	40	40
		Tuba aperta d. A. dxt. see page 105.											
		A. sin. Dry. Defect in pars tensa	L.			12	36	12	48	15	66	85	85

86	M. 13	Otit. med. supp. chr. d. Otit. med. supp. chr. s. seq. A. dxt. Marginal defect. Granulations. A. sin. Cicatrix	R. L.	0 26 22 34	5 25 29 40	11 24 55 70	7 36 0 Min.	45 35 0 0
88	M. 23	Otit. med. supp. chr. d. Otit. med. supp. chr. s. seq. A. dxt. Pus. marginal perf. upwards posteriorly. A. sin. Cicatrix	R. L.	9 33 11 32	15 35 15 37	25 44 33 62	40 70 46 58	30 20 0 0
89	M. 29	Otit. med. supp. chr. d. + s. seq. A. dxt. Large retracted cicatrix A. sin. Large Cicatrix	R. L.	0 48 0 52	0 57 0 62	0 75 6 85	16 92 19 106	45 40 25 20
90	M. 12	Otitis catarrhalis d. + s. — occlusio tubarum A. dxt. + sin. Drums retracted, somewhat red	R. L.	2 24 2 25	3 26 0 27	5 29 7 30	7 36 9 37	55 55 50 55
95	W. 19	Otitis catarrhalis acuta d. + s. A. dxt. + sin. Drums red, retracted	R. L.		3 29 5 28	13 37 11 33	18 39 23 35	35 40 30 30
103	W. 22	Otit. med. supp. chr. d. seq. A. dxt. Dry. Total defect of pars tensa. A. sin. Perception affection.	R.	0 34	0 42	0 50	9 68	35 30

one exception. This ear (No. 51, right) is discussed on page 105. A completely patent tuba — perhaps in connection with a large mobile cicatrix, explains the high Abs.

The Phase in most of the ears is fairly small. Some ears have a higher Phase, especially the ear with the constantly

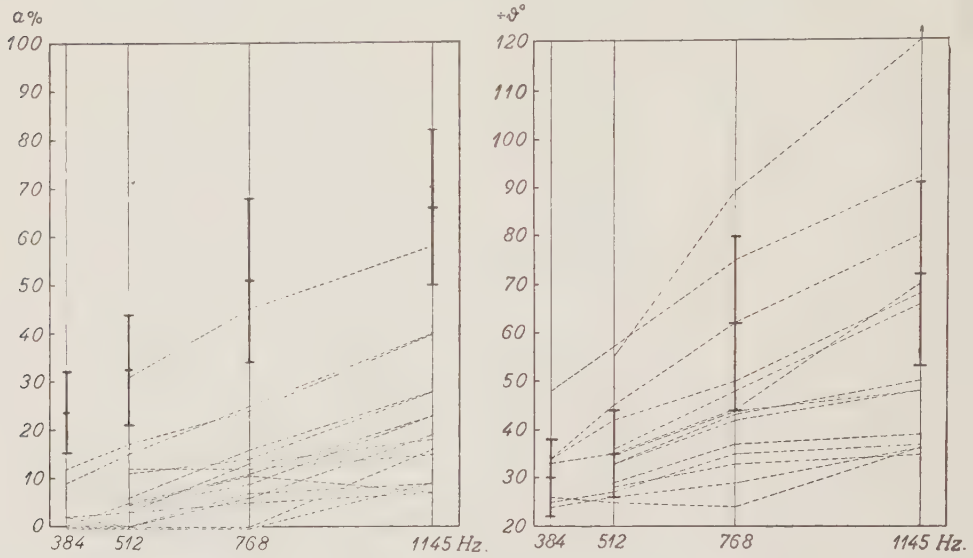


Fig. 18. Conduction affections with changes of the drum on account of inflammations or sequelae of such (Abs. and Phase curves).

open Eustachian tube described. The Phase is here so high, particularly for 768 and 1145, that this ear also in regard to the Phase differs from the other ears with conduction affections. The Imp. in Fig. 19 is noted in the complex plane. The Imp. for the 10 ears with conduction affections described in the previous chapter is likewise noted here.

Of the 25 examined ears with conduction affections with this etiology only 3 have a high Abs.

For the remaining 22 ears the mean value and standard deviation of the Abs. are:

384 Hz.	$6.3 \pm 5.3\%$	512 Hz.	$8.8 \pm 5.5\%$
768 Hz.	$14.0 \pm 6.9\%$	1145 Hz.	$20.4 \pm 9.4\%$

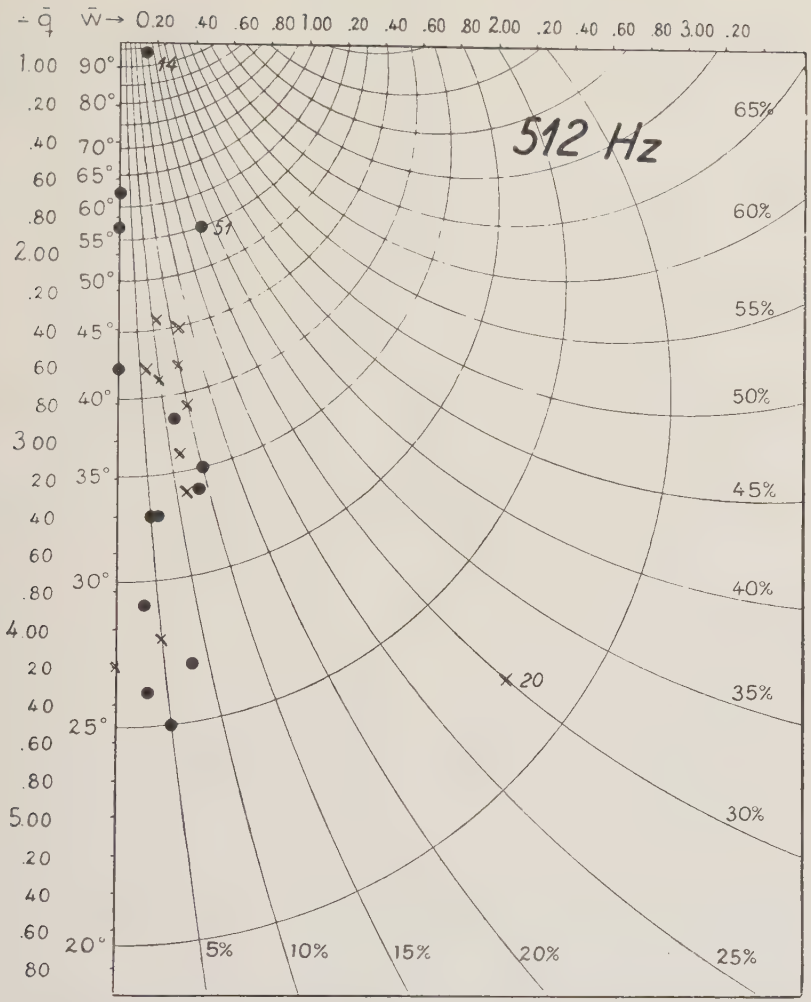


Fig. 19. The Imp. of all the examined ears (25) with conduction affections on account of inflammations or sequelae of such, noted in the complex plane (cf. Fig. 12).

There is a question of ears with the most different changes of the drum, but the material is too small to permit of grouping them with regard to the diagnosis or the features of the drum. In more a comprehensive material such a grouping would be of importance in order to see, if there is a connection between

diagnosis (respectively features of the drum) and the change of the Imp. The Abs. almost always becomes smaller, but it might be thought to be possible to find a connection between the change of the Phase, which in these small values of the resistance (w) correspond to a pure change of the reactance component (q), and various pathologico-anatomical changes, i. e., the physical cause of the conduction affection.

Of the ears noted in Table 12, with changes of the drum but with normal hearing for the frequencies used in the measuring of the Imp., No. 8 was only examined for whisper, the other 3 audiometrically.

The Abs. for No. 8 right and No. 86 left ear, is quite within the normal range, for 88 left ear, it lies fairly low.

No. 45 left, had a slight loss of hearing for 256 Hz. (15 db). The Abs. lies fairly low for 512 Hz., increasing for the next two frequencies (just as the hearing).

VIII. IMPEDANCE MEASURING ON A MATERIAL OF PATIENTS WITH IMPAIRED HEARING AND NORMAL EAR DRUMS

A. SELECTION OF PATIENTS

We have examined 47 cases with impaired hearing and normal ear drums. The material comprises patients from my private practice, besides odd cases of Morbus Ménière admitted to the Otological Department of the Rigshospital, a few other hospitalized patients and some cases from the Out-patient Clinic of the Rigshospital.

The impairment of hearing has in most cases been considerable. We have especially attached importance to this in the cases of perception affections.

The ear drums are perfectly normal in most cases, but we have included also single ears with very slight changes (f. i. a little dull or sclerotic drums, one slightly retracted (doubtful)). As, for the above mentioned reasons, we have not examined

patients with very narrow ear canals, there has in some degree been a selection of the material according to the width of the ear canal.

A selection of the cases (with exception of the Ménière cases) has further been made in preferring "clear-cut cases", i. e., either perception or conduction affections. The reason is that impedance measuring only can be expected to afford the diagnosis of sound conduction affections. The complicating perception or conduction affection will only contribute to make diagnosis and grouping according to the subjective function tests more difficult. In some cases, however, hard hearing of combined type has been included, for example if this was ascertained first during or after the examination. Thus the selection has not been very rigorous. No patient who has come to measuring of the Imp. has been excluded.

B. EXAMINATION OF AUDITION

We have used a Western Electric Audiometer, type 6 A., the same apparatus which was controlled and used by *Foght* 1—2 years earlier. It has been controlled at intervals since then. The oscillations at the lowest and highest frequencies are not quite sinus-shaped. The step graduation of the attenuator is good with the exception that the upper limit for all tones is about 10 db below the highest number of the scale for each frequency.

All the audiometer tests have been made in a sound-proof room at the ear clinic of the Rigshospital. Only the passing of tram cars was heard as a slight noise in the room.

The procedure has been as that which Foght, among others describes it. The tone has been changed in steps of 5 db usually from audible to threshold value as well as from tone below the threshold. We have made air conduction audiograms of all patients, using the frequencies between 128 and 8192 Hz.; in the cases of bilateral impairment of hearing also bone conduction audiograms were made. In cases of unilateral impairment of hearing we have usually made Fowler's balance test. (See Fowler's papers regarding this theory and technique).

We have further in some cases made the usual function tests for the determination of the lower and upper hearing limit for air and bone conduction, air and bone conduction determination with a^1 tuning-fork, Rinne's and Weber's tests. These tests have not been made in the sound-proof room. We proceeded in the same manner as employed in the Danish clinics which have been described f. i. by *Börge Larsen.*

All the function tests have been made before the measuring of the Imp., as we had to reckon with the possibility of tiredness of the ear for the frequencies employed.

In quite a number of cases it was necessary to make the fewest possible function tests. It was often hard to get the patients for examination more than once. The time had then mainly to be used for the measuring of the Imp., which in all these cases has been done with special care and has taken much longer time than would usually have to be reckoned with for ordinary clinical use.

For some of the patients who have been treated at the ear clinic of the Rigshospital we have used audiograms which have been made by a specially trained assistant of the clinic.

C. GROUPING OF THE MATERIAL ACCORDING TO THE SUBJECTIVE FUNCTION TESTS

For diagnostic reasons the patients were primarily divided into cases with unilateral or bilateral hard hearing. The bilateral cases either had an equal reduction of hearing on both ears or there was a more or less pronounced difference.

Afterwards each of the two groups has been divided into 1) conduction affections, 2) perception affections, and 3) doubtful diagnoses according to the following lines of direction.

Unilateral reduction of hearing.

This material consists of 19 patients.

Fowler's test has been made in 14 cases. According to the result one case was recorded as conduction affection, 10 as perception affections, and 3 as doubtful. Three patients were quite deaf on one ear after parotitis. They were also placed

among the perception affections. There are now 2 cases left, in which the diagnosis was made according to the ordinary function test.

Bilateral reduction of hearing.

28 patients of this type are divided mainly in regard to the relation between bone conduction and air conduction, a classification which was used and recommended by *Foght* in a Danish thesis 1943.

In perception affections the hearing is equally reduced for bone conduction and air conduction. The proportion will thus be about 1.

In conduction affections bone conduction is often normal, but may be more or less reduced. The proportion bone conduction/air conduction will probably be about 0 or between 0 and 1. It may be assumed however that the proportion seldom in conduction affections reaches 1.

Bone conduction has not been examined with "masking" of the opposite ear. It is therefore impossible to determine the proportion between bone conduction and air conduction for each ear separately, but one must choose if one wishes to compare the bone conduction values found (from the proc. mast.) with air conduction from the best or the worst ear or possibly both air conduction values with one of the bone conduction values.

As one cannot find a method rational in all cases, *Foght* chooses to use air conduction from the best ear and compare it with the bone conduction values for each ear separately.

We find it more reasonable to choose the best bone conduction, it is anyhow impossible to know of which ear the bone conduction has been determined, and compare it with the air conduction of both ears.

It has at any rate the advantage that it makes it possible on a diagram to read the difference of air conduction between the left and right ear, which is of importance for the estimation, if the number of the patient is quoted at each measuring value. That is possible in as small a material as the present. Therefore this method is chosen here. A classification after Foght's

method will indeed give the same results, if the boundary line indicated below is used (a single patient Nr. 53 with perception affection and fairly great difference of hearing on the two ears will thus be recorded as dubious, however).

The classification has been made so that we have allowed a certain dispersion of the proportion around 1. In reality only the lower limit is of importance. It has roughly been set at 2/3. What is equal to or above this proportion is called perception affection. Values lying beneath this proportion have been counted as conduction affections. Among them will also be found possible cases of combined hard hearing, but for a later comparison with the results of the measuring of the impedance, it is, as already mentioned, of most importance to make the differential diagnosis: conduction affection — non-conduction affection. For the time being it can only be expected that by measuring the impedance, combined hard of hearing is diagnosed as conduction affection.

Conditional for judging in this way is that there is only a slight difference of hearing between the right and left ear. It has been reckoned with that the difference is less than 25 db, and in most cases it is considerably less.

As a basis for the classification was utilized the proportion bone conduction/air conduction at the two audiometer values lying in the range of frequencies comprising the measuring of the Imp., i. e. 512 and 1024 Hz.

18 Patients (out of 28) can on this basis be divided into conduction affections (8) and perception affections (10) as the proportion for both ears and both frequencies lies above or below 2/3.

7 patients cannot be classified in this way, as either the right or the left ear lies each in its field at the same frequency or both ears lie in one field for one frequency and in the other for the other frequency.

3 patients cannot be classified in this way because there is too great a difference of hearing between the two ears. On two of these patients Fowler's test was made, and the result was one perception and one conduction affection.

One patient + the afore-named 7 patients were classified

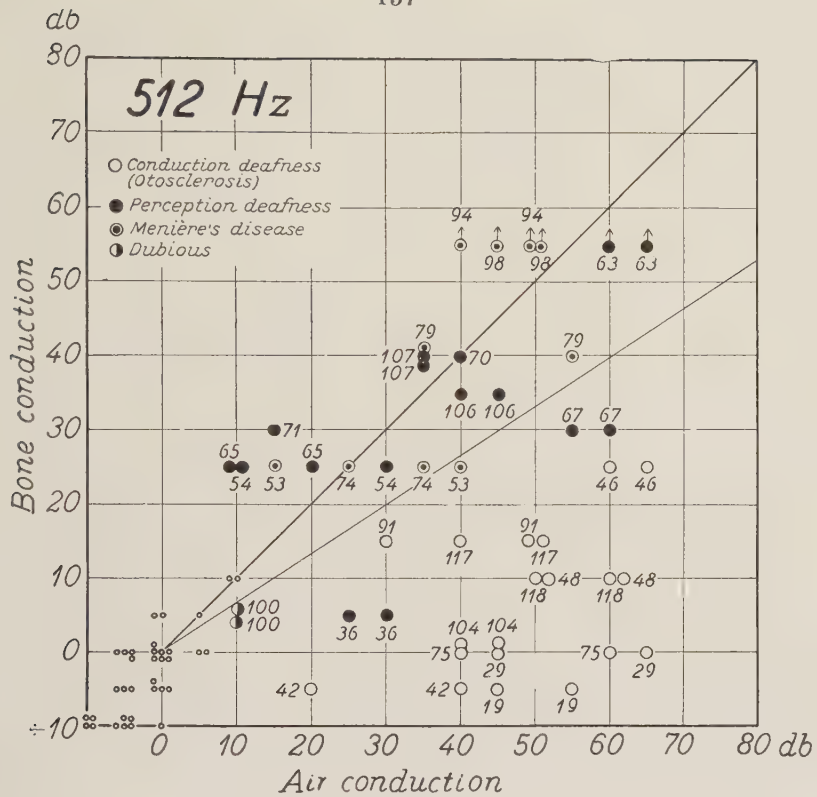


Fig. 20.

Fig. 20 and 21. The proportion between bone conduction and air conduction for 512 and 1024 Hz. in 25 patients with bilateral impairment of hearing and normal ear drums.

The two oblique lines represent respectively the proportion between bone conduction and air conduction 1 and 2/3. The small dots around the zero point of coordinates are the values for a normal material (after *Foght*) measured with the same audiometer.

according to the estimation of the remaining hearing-tests inclusive of the proportion bone conduction/air conduction at the other frequencies.

Fig. 20 and Fig. 21 show the 25 patients in whom the difference between the two ears is less than 25 db, recorded graphically on the diagram so warmly recommended by *Foght*. Air conduction is plotted as the axis of abscissae, and the

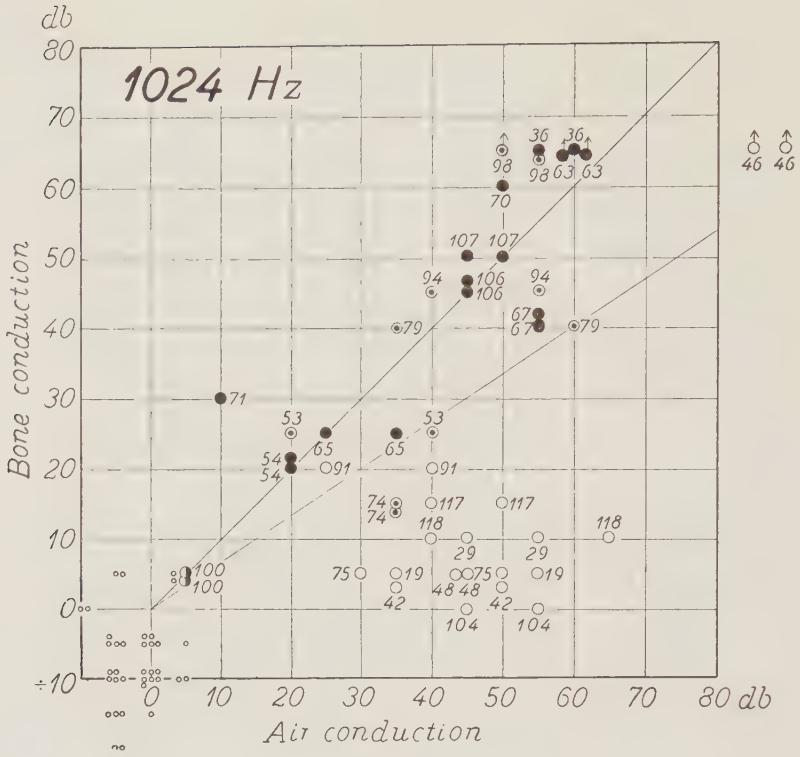


Fig. 21.

bone conduction in db as ordinates. O db is placed in the zero point of the coordinates (in opposition to *Foght*'s diagrams, where the db values rise towards the zero point, whence the values for the normal lie upward to the right).

From the zero point on the diagrams that line is drawn whose incline towards the axis of abscissae is 0.67, i. e., tg. to the angle between the axis of abscissae and the line is 0.67.

The ears which lie below this line are thus regarded as conduction affections, those which lie on or above it, as perception affections.

Foght uses the proportion bone conduction/air conduction to show, and this way of delineating to illustrate that, in a material of hard-hearing patients with normal ear drums, selected at random, the patients may be divided into 2 chief groups. Here this proportion is used only to classify the ma-

terial in order to make possible a subsequent comparison with the classification according to the impedance measurements, which is quite independent of it.

Table 13 shows this distribution according to the subjective function tests both for the patients with unilateral and bilateral hard-hearing, recorded with information as to which patients

Table 13. Classification of the material. (47 hard-hearing patients with normal ear drums).

Unilateral impairment of hearing				Bilateral impairment of hearing			
Conduction affections	Perception affections	Ménière's syndrome	Doubtful cases	Conduction affections	Perception affections	Ménière's syndrome	Doubtful cases
21 — F	50 — F	28 F	73 F	19 m	36 t	32 F	100 t
66 F	77 F	37 F	112 F	29 m	54 s	53 t	
	83 surd	68 F	113 F	42 m	63 s	74 t	
	102 F	80 F		46 t	65 s	79 s	
	105 F			48 m	67 t	94 s	
	110 F			52 F	70 s	98 s	
	115 F			75 m	71 s		
	119 F			84	106 s		
	120 surd			91 t	107 s		
	121 surd			104 m			
				117 m			
				118 m			
2	10	4	3	12	9	6	1
	19				28		

F = Fowler's test, — F = Fowler's test not made. surd. = perfectly deaf on one ear. m, s, and t refer to the proportion between bone and air conduction; m means that the proportion is less than 2/3, s meaning it is higher than or equal to 2/3 for both ears for 512 and 1024 Hz., t, that the patient cannot be classified in this way. No letter or only F for the bilateral impairments of hearing indicates that they cannot be classified after the relation bone conduction/air conduction on account of too great a difference in the hearing (above 25 db).

are classified in the different groups. The letters indicate what patients are grouped after the result of Fowler's test (F), and what patients are grouped after the proportion bone conduction/ air conduction (*m* and *s*), the table moreover showing which of the unilaterally hard-hearing patients have not been submitted to Fowler's test, and which of the bilaterally hard-hearing cannot be judged after the proportion between bone conduction and air conduction (on account of the great difference of audition) (no letter), further which of the bilaterally hard-hearing patients present a doubtful result (*t*) of this proportion.

Accordingly the patients are collected in the 4 chief groups which are of importance for the Imp. measurements: Conduction affections, perception affections, Ménière's syndrome, and dubious diagnoses with unilaterallity and bilaterallity as sub-groups.

CASE REPORTS

CASE REPORTS

The case reports are collected in the mentioned 4 groups: conduction affections, perception affections, mb. Ménière, and uncertain diagnoses with unilaterality and bilaterality as subgroups.

In the Tables recording the "impedance measurings" the following abbreviations are used:

$a = a\,\% =$ Abs.; $v = -\vartheta^\circ =$ the Phase; $w = \bar{w} \cdot 100$; $q = -\bar{q} \cdot 100$; M.R. = the muscle reflex.

R. H. Pol. = Out-patient Clinic of the Rigshospital.

R. H. ward = Ear Clinic of the Rigshospital.

Otherwise only the abbreviations generally applied in the otological literature are used.

In cases in which nothing special is noted the hearing is unchanged after tuba-catheterization and *neither* buzzing *nor* giddiness has been observed.

CONDUCTION AFFECTIONS WITH NORMAL EAR DRUMS

Unilateral conduction affections with normal ear drums.

No. 21. W. 37 years. 1937 Sinusitis maxillaris d + s. Pus was found in both maxillary sinuses. 1938 Claoués operation was made on the right side. 1940 Resectio sinus maxillaris dxt. *a. m.* Denker. Still pus especially from the right side of the nose.

During a couple of years cutting pains now and then in the right ear. Only a few days without pains. During the same period the hearing is reduced on the right ear, especially during the last 1/2 year. No tinnitus. Never discharge.

A. d. + s: Drums quite normal. Large auditory canals.

Cav. nasi: Mucosa red. Some mucopus scattered on both sides. Good access to the right sinus. No pus to irrigate.

Rh. ph.: Mucosa somewhat red. Tuba openings uniform, perhaps a little swollen.

v: 0.30—1.50/>7.00 (48—27). a^1(a): 28/57 (60); a^1 (m): 15/15 (20)

R: —/+. W: Lateralization to the r. Li: 36/26. Ls (a): 15000/15000.

Conclusion: Elevation of lower limit. Normal upper limit. Weber: lateralization to the pathological side.

Diagnosis: Otitis catarrhalis chr. dxt.

Impedance measuring (28/10 41):

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
384	11	34	35	325	26	30	105	345
512	13	46	25	235	36	40	87	249
768	19	63	19	162	51	76	44	118
1145	47	92	30	92	76	75	77	96

No. 66. W. 29 years. Mother and maternal aunt hard of hearing at the age of 50. Patient has for about 1 year noticed reduced hearing on the right ear. Strong buzzing for about 1 hour at a time several times a day.

A. d. + s: Drums normal.

v: 0/>6.00. V: 0.10/Ba. W: Lateralization to the right. Li: 150/16.
Ls (a): 12000/15000. Ls (m): 15000/16000.

Audiogram and Fowler's test (22/6 42): p. 193.

Conclusion: Familial deafness. Considerable elevation of lower limit. Very slight lowering of Ls. Weber towards the affected side. Audiogram (air conduction): Reduction of hearing to 1024, subsequently increasing to 8192, where it is best. Fowler: 256, 512, and 1024 no regression, with 2048 and 4096 some regression.

Diagnosis: Conduction affection (perhaps + perception affection for the higher frequencies). Otosclerosis?

Impedance measuring (22/6 193):

	Right ear				Left ear				
	a	v	w	q	a	v	w	q	
384	0	28	0	402	11	22	74	505	
512	4	30	17	374	16	24	100	452	
768	9	36	24	307	38	37	105	262	
1145	23	47	41	225	57	42	126	193	
768		MR —			39	38	103	254	
—					19	33	63	327	MR
—					39	38			
512		MR —				MR +			

Bilateral conduction affections with normal ear drums.

No. 19. M. 54 years. Mother hard of hearing at the age of 50. She is now 80 years and very deaf. The hardness of hearing of the patient has slowly increased during several years. There is tinnitus in both ears.

Unilateral conduction affections. — Bilateral conduction affections.

A. d. + s: Drums normal. Large auditory canals.
v: 0,20/0,10. V: 1,50/0,20. a^1 (a): 20—19/15—13 (90). a^1 (m): 23/28 (25). R: —13/—19. W: Lateralization to the left. Li: 55/150. Ls (a): 6000/<6000. Ls (m): 14000/14000.
Audiogram (20/10 41): p. 193.

Conclusion: Familial deafness. Bone conduction absolutely prolonged (tuning fork in ordinary room) W: lateralization to the worst ear. Considerable elevation of lower limit. Good Ls. (determination of bone conduction with monchord).

Audiogram: Considerable loss of hearing, increasing to the highest frequencies. Bone conduction normal for the lower frequencies.

Diagnosis: Otosclerosis.

Impedance measuring (20/10 41):

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
384	9	25	55	445	9	25	55	445
512	11	32	45	350	11	34	35	330
768	17	47	39	228	25	43	53	246
1145	46	62	54	153	46	72	43	130

Impedance measuring (15/12 41):

384	10	30	40	370	12	30	49	368
512	10	33	33	335	15	33	49	332
768	21	50	32	211	28	52	42	199
1145	35	63	38	157	44	74	39	126

512 og 768: MR — MR —

No. 29. M., aged 39 years. R. H. Pol. 5026/41. In 1931 treated for otosclerosis duplex. (R. H. Pol.) Now he complains of deafness and buzzing in both ears, though mostly on the left side. For two years the patient has suffered from attacks of giddiness, nausea and vomitings.

Never discharge. Has not been working in noise. No familial disposition to hardness of hearing.

A. d. + s: Ear drums normal. v: 0.10/0.10. No spontaneous nystagmus.
W. R. (in blood): 6. Kahn 4.
Spinal fluid: 399/3 cells. Albumin 30. Globulin 20. W. R.: 6.
Diagnosis: Cerebrospinal syphilis. Audiogram: p. 193.

Conclusion: Air conduction: Considerable hearing loss, increasing towards the medium frequencies, whence about constant.

Bone conduction: About normal for the low frequencies, decreasing at 2048 and 4096, being perfectly normal at 8192 however.

Diagnosis: Otosclerosis?

Impedance measuring:

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
384	6	39	12	284	17	43	34	251
512	5	48	9	225	24	48	41	219
768	10	68	8	149	33	70	30	139
1145	36	80	26	116	36	86	23	105
512 and 768:	MR —				MR —			

No. 42. W., aged 38 years. The father rather deaf. Patient has experienced increasing impairment of hearing during the last couple of years. Buzzing in both ears.

A. d. + s: Ear drums normal. Auditory canals fairly narrow. v: 0.05/0.40. Audiogram (23/2 42): p. 193.

Conclusion: Familial hardness of hearing. Audiogram: Increasing hearing loss towards the medium frequencies, better audition at the higher frequencies. Normal bone conduction for the low frequencies.

Diagnosis: Otosclerosis.

Impedance measuring (23/2 42):

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
384	7	28	30	400	0	27	0	417
512	13	29	56	381	0	29	0	388
768	25	43	52	245	13	34	42	324
1145	38	58	48	171	23	42	50	253
512 and 768:	MR —				MR —			

No. 46. M., aged 28 years. At the age of 23—24 years incipient hard-hearing. Since that time his audition has decreased gradually. Now and then buzzing.

A. d. + s: Ear drums normal. v: 0/0. V: 0.05/0.05.
Li: 60/60. Ls (a): <6000/<6000. Ls (m): <6000/<6000. R: —/—. Audiogram (10/3 42): p. 193.

Conclusion: On account of the relatively good bone conduction for 256 and 512 Hz., which manifests itself also in the negative Rinne test, it is thought to be a question of conduction affection, even though it certainly is complicated with a perception affection.

Diagnosis: Otosclerosis? + perception affection.

Impedance measuring (3/3 42):

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
512	15	37	40	295	9	35	26	316
786	21	55	27	190	14	47	24	229
1145	52	79	42	113	32	63	34	159
512 and 768:	MR —				MR —			

Bilateral conduction affections.

Impedance measuring (10/3 42):

512	0	39	0	284	0	37	0	300
768	9	44	17	247	9	44	17	247
1145	27	54	37	192	31	56	41	181

512 and 768: MR — MR —

No. 48. M., aged 66 years. R. H. Pol. 679/42. The patient's mother and brother are reported to have been hard-hearing. The patient's audition has been reduced on both ears from his 20th year. Never discharge or pain. Now and then a little giddiness.

A. d. + s: Both ear drums are slightly sclerotic, otherwise normal.
v: 0.20/a.a. V: 4.00/2.00. W. R.: —.
Audiogram: p. 193.
Diagnosis: Otosclerosis.
Impedance measuring:

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
512	9	34	27	327	1	36	6	309
768	12	48	21	223	10	45	19	240
1145	32	58	40	174	39	48	69	206

512 and 768: MR — MR —

No. 52. W., aged 34 years. A maternal aunt hard-hearing. At the age of about 18 years the patient became aware of incipient deafness on her right ear. Since then her audition has gradually decreased. 7 or 8 years ago an attack of vertigo which occasioned several days' confinement to bed, but has not recurred. Sometimes buzzing before the right ear.

A. d. + s: Ear drums normal. v: 0.10/8.00.
Audiogram (15/4 42) and Fowler's test: p. 193.

Conclusion: Audiogram. Air conduction: Considerable hearing loss on the right ear, particularly for the low and medium frequencies. Slight hearing loss on the left ear, most pronounced in the same range of frequencies.
Bone conduction: Normal in the whole range.
Fowler's test: Absolutely no regression at 512 Hz., some regression at 1024.
Diagnosis: Otosclerosis.
Impedance measuring (15/4 42):

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
512	10	30	37	370	8	29	32	386
768	24	42	52	252	21	37	56	290
1145	62	52	100	157	67	48	119	153

512 and 768: MR — MR —

No. 75. M., aged 44 years. During the last 6 years the patient has experienced gradual impairment of hearing. His father probably is somewhat deaf too.

A. d.: Tympanic membrane somewhat retracted.
A. s.: Tympanic membrane normal. Large auditory canals.
v: aa/0.20. V: 0.20/1.00.
Audiogram (25/8 42): p. 193.

Conclusion: Considerable hearing loss per air conduction. About normal bone conduction up to 1024 Hz.
Diagnosis: Otosclerosis.
Impedance measuring (25/8 42):

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
384	0	41	0	268	2	36	5	309
512	0	47	0	231	2	41	4	268
768	5	63	5	164	11	56	14	188
1145	18	74	14	132	31	72	27	135

512 and 768: MR — MR —

No. 84. W., aged 41 years. During the last couple of years impairment of hearing particularly on the right ear. Constant, strong buzzing in both ears.

A. d. + s: Ear drums normal. Large auditory canals.
v: aa/0.20. Li: 90/55. Ls (a): <6000/9000.
Ls (m): 9000/12000.
Audiogram (14/9 42): p. 194.

Conclusion: Considerable elevation of Li, fairly good Ls per bone conduction.
Diagnosis: Conduction affection. — Otosclerosis?
Impedance measuring (14/9 42):

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
384	4	28	18	400	7	29	28	385
512	6	30	24	372	9	33	30	336
768	13	40	31	274	19	42	40	256
1145	33	50	54	203	50	66	54	140

512 and 768: MR — MR —

No. 91. W., aged 20 years. Increasing deafness during the last years, particularly during the last 4 or 5 months. For about 3 months sensation of resonance in the right ear, and autophony.

A. d. + s: Ear drums normal. Fairly large auditory canals.
v: 2.00/1.00. Li: 70/90. Ls (a): 12000/10000. Ls (m): 14000/14000.
Audiogram (25/9 42): p. 194.

Conclusion: Considerable elevation of Li, fairly good Ls per bone conduction. Audiogram. Air conduction: Moderate hearing loss, most pronounced for the left ear. Hearing loss equal up to the highest frequencies, where audition becomes better. Bone conduction: Particularly for the lower frequencies much better than air conduction.

Diagnosis: Conduction affection. — Otosclerosis?

Impedance measuring (25/9 42):

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
384	2	31	9	363	1	31	5	363
512	6	32	22	348	5	35	15	317
768	15	46	26	234	13	47	23	229
1145	34	61	39	164	34	61	39	164

512 and 768: MR — MR —

No. 104. W., aged 28 years. R. H. Pol. 2039/42. For several years gradual impairment of hearing. Constant buzzing. Sometimes a little giddiness.

A. d. + s.: Ear drums somewhat dull and retracted. Very narrow auditory canals. (7 mm. tube reaches but little into the cartilaginous auditory canal).

v: 1.00/0.30. No spontaneous nystagmus.
Audiogram (7/12 42): p. 194.

Conclusion: Audiogram. Air conduction: Considerable hearing loss, most pronounced for the low frequencies. At 8192 Hz. the curve drops considerably however. Bone conduction: Normal for 512 and 1024 Hz.

Diagnosis: Conduction affection. — Otosclerosis?

Impedance measuring (7/12 42):

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
384	7	20	58	562	0	23	0	492
512	10	22	68	506	0	27	0	417
768	21	26	110	406	8	24	46	466
1145	15	30	60	365	22	30	90	353

512 and 768: MR — MR —

No. 117. W., aged 38 years. The mother hard-hearing since the age of about 40 years. The patient herself about 10 years ago became aware of incipient impairment of hearing, to begin with on the left ear, later on the right ear also. Buzzing in both ears. Sometimes a little vertigo.

A. d. + s.: Ear drums normal.
v: 0.10/aa. V: 2.00/0.10. Li: 65/90. Ls (a): 9000/9000.
Ls (m): 14000/14000. R: —/—.
Audiogram (19/3 43): p. 194.

Conclusion: Considerable elevation of Li., good Ls. per bone concluction. R: negative. Audiogram: Bone conduction in the whole range better than air conduction.

Diagnosis: Otosclerosis.

Impedance measuring (19/3 43):

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
512	5	37	13	299	4	38	10	290
768	14	55	18	191	7	58	9	181
1145	22	92	12	96	14	92	7	97

512 and 768: MR — MR —

No. 118. M., aged 47 years. Disposition to hardness of hearing in the mother's family. Patient at the age of about 27 became aware of incipient hardness of hearing. Has been working in strong noise 1917—1920, not since that time. In 1919 malaria, treated with quinine. Patient was not deaf at that time.

A. d. + s.: Ear drums normal. Large auditory canals.
v: 0/aa (partially). V: 0.10/0.30.
Audiogram (30/4 43): p. 194.

Conclusion: Audiogram. Bone conduction about normal at the low frequencies, at the high frequencies also much better than air conduction.

Diagnosis: Otosclerosis.

Impedance measuring (30/4 43):

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
384	5	32	18	349	13	41	30	266
512	1	40	3	275	10	41	22	267
768	6	50	9	215	22	57	27	182
1145	24	62	26	164		0 Minimum		

512 and 768: MR — MR —

PERCEPTION AFFECTIONS

Unilateral perception affections.

No. 50. M. 31 years. R. H. Pol. After a blow on the head in September 1939 some fits of giddiness. At that time no symptoms from the ears. Was

treated in the Dept. A of the Rigshospital Dec. 1939. Examination esp. Roentgenogram of the skull: Nothing abnormal.

Otological examination showed: v. >12.00/>12.00.
Li: 16/16. Ls. (a): 19000/19000.

No spontaneous nystagmus. Caloric reaction normal, equal on both sides.
The hearing of the right ear has since then been steadily decreasing. No vertigo, but buzzing in the right ear.

A. d. + s.: Drums normal. v. 0.50/>12.00.
Caloric reaction normal.
Audiogram: (11/3 42): p. 195.

Conclusion: Judging from the anamnesis it is probably a perception affection.
Impedance measuring (11/3 42):

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
512	41	28	175	309	22	22	154	466
768	64	61	82	135	40	35	121	269
1145	82	74	87	86	59	53	93	161
512 and 768: MR —					MR —			

No. 77. M. 36 years. Father suffered from hardness of hearing and from buzzing on the right side. For about 10 years the patient has noticed hardness of hearing of the right ear. Has remained unchanged. All the time buzzing in the same ear. 1935 lues diagnosed. No symptoms. Blood test was made because of the loss of hearing. Was treated. Yearly control. W. R. now negative.

A. d. + s.: Drums normal. v. aa/3.00. V: 1.00/Ba.
Audiogram (26/8 42) and Fowler's test: p. 195.

Conclusion: Audiogram: On the right ear loss of hearing in the whole range of frequencies, increasing towards the high frequencies.
The hearing on the left ear normal except for the highest frequencies, where the loss of hearing is almost as great as for the right ear.
Fowler's test: Perception affection.
Impedance measuring (26/8 42):

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
384	19	33	63	327	20	35	60	307
512	24	39	60	273	26	40	62	263
768	51	74	46	122	48	67	51	140
1145	90	110	68	45	67	74	66	110
512 and 768: MR + (weak)					MR —			

No. 83. W. 27 years. Deaf on right ear for one year, after parotitis. No vertigo. No pains or discharge. No symptoms from the left ear.

A. d. + s.: Ear drums normal. Large auditory canals.
v: 0/>12.00. V: 0/Ba. Caloric reaction is elicited from the right ear.

Conclusion: Right-sided total deafness in sequel to parotitis.
Impedance measuring (7/9 42):

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
384	23	24	140	430	20	22	142	475
512	38	26	186	339	29	20	230	454
768	54	47	101	186	48	40	116	224
1145	60	64	71	135	62	53	61	116
768	54	46						
—	29	46	MR				MR —	
—	55	48						

No. 102. M. 36 years. Both parents suffered from hardness of hearing on the right ear. At the age of about 6—7 years patient had discharge from the right ear. No other symptoms from the ears before about 6 months ago when he noticed hardness of hearing on the right ear. The hearing has not decreased during the last half year.

A. d. + s.: Drums normal. v: 0.20/>6.00. V: >6.00/>6.00.
Audiogram (1/12 42) and Fowler's test: p. 195.

Conclusion: On the pathological ear there is heavily impaired hearing for whisper, fairly good hearing for spoken voice. Fowler: Perception affection.
Impedance measuring (1/12 42):

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
384	22	42	47	254	24	40	57	265
512	30	51	47	201	32	49	54	209
768	60	90	43	90	59	85	45	99
1145	90	112	67	43	82	102	61	61
512			MR —		34	49		
—					17	46	MR	
—					32	48		

No. 105. W. 56 years. R. H. ward. 5474/42. During the last 1/2 year decreased hearing on left ear and buzzing on this ear. Was treated for gall stones in hospital. During the same time vertigo of very short duration (a

few seconds). It occurred when walking, never while at rest. Has never fallen. Never pains in the ears or discharge.

A. d. + s.: Drums normal. Auditory canals rather narrow.
v: 5.00/0. V: Ba/0.75.
Audiogram (7/12 42) and Fowler's test: p. 195.

Conclusion: Audiogram (air conduction): Good hearing for the low frequencies. Bone conduction reduced. Fowler: Perception affection.
Impedance measuring (7/12 42):

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
512	15	37	48	292	32	35	97	288
768	33	58	42	174	65	62	82	132
1145	67	74	66	110	73	55	109	126
512 and 768: MR —					MR + (weak)			

No. 110. M. 12 years. No hereditary hard hearing. Oct. 42 parotitis epidemica. Temp. reached 104° F. Abt. one month later adeno-tonsillectomy. After this operation deficient hearing of the left ear was noticed at school. The hearing had formerly been good. No vertigo.

A. d. + s.: Drums normal. Auditory canals fairly wide.
v: >5.00/0. V: Ba/0.10.
Rhinopharynx: No adenoid vegetations.
Audiogram (25/1 43) and Fowler's test: p. 195.

Conclusion: Hearing loss developed after parotitis epidemica. Considerable loss of hearing in the whole range of frequencies. Fowler: Perception affection.
Impedance measuring (25/1 43):

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
384	24	23	156	439	20	21	156	496
512	31	25	168	381	27	27	130	375
768	45	46	87	206	37	41	86	243
1145	62	67	69	127	51	60	65	154
512					28	27		
—		MR —			16	29	MR	
—					28	27		
768		MR —						

No. 115. M. 26 years. Grandfather suffered from hard hearing and an uncle incurred the affection at a rather young age. As a child patient sometimes had discharge from probably the left ear. At a hearing test in school the

hearing on the left ear was slightly less than on the right ear. Never discharge since childhood.

During the last years the hearing on the left ear has decreased. Has never been able to use this ear in telephoning. Now and then buzzing (in the left ear). Until about a year ago the patient worked for two years in heavy noise, but he thinks the reduction of hearing was pronounced before that time.

A. s.: A whitish falciform infiltration downward posteriorly, the drum is otherwise normal.

A. d.: As the left ear but only indicated.
v: >6.00/0.50. Li: 17/26. Ls (a): 14000/8000.

Weber: lateralization to the right. a^1 on left proc. mast. is heard with the right ear, and not heard by masking of the right ear with Bárány's noise apparatus, but well in the opposite direction (a^1 on right proc. mast. and masking of left ear).

Audiogram (9/3 43) and Fowler's test: p. 195.

Conclusion: Audiogram: (air conduction). Fairly considerable loss of hearing, about equal for the whole range, except 8192 where the hearing loss is greatly increased. Ls (a) fairly good however. Only slight elevation of Li. Weber: Lateralization towards the normal ear.

a^1. is not heard per bone conduction when the normal ear is „masked".

Fowler: Perception affection.

Impedance measuring (9/3 43): Only made from one frequency (512 Hz.).

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
512	32	42	71	244	35	52	53	194
512		MR —			34	50		
—					20	49	MR	
—					33	48		

No. 119. M. 26 years. About 10 years ago (16 years old) the patient reports that he became suddenly totally blind. At the same time unilateral reduction of hearing and pressure and buzzing on the left ear. No other symptoms were noticed, especially no vertigo and no loss of consciousness. The sight became normal again after about 20 minutes and has been normal since then.

The hearing improved but not totally and has since then steadily been decreasing (on the left ear). No buzzing now. During the same time (10 years) now and then very short attacks of vertigo. He once fell. Never vomiting.

A. d. + s.: Drums normal.
v: >6.00/0.40. No spontaneous nystagmus. Caloric reaction normal.

Neurological examination (R. H. Pol.): No signs of an organic nerve disease.

Ophthalmological examination: Nothing abnormal.

The short amblyopia may be caused by a spasm of the retinal blood vessels.

Roentgenogram of the temporal bone: Nothing abnormal.

Audiogram (3/5 43) and Fowler's test: p. 195.

Conclusion: The anamnesis very suggestive of perception affection.

Audiogram: (air conduction): Slight loss of hearing strongly increasing towards the higher frequencies.

Fowler's test: Perception affection.

Impedance measuring (3/5 43):

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
384	36	20	264	400	54	22	268	252
512	52	24	244	263	54	28	205	243
768	63	51	105	157	73	62	93	117
1145	81	66	97	95	89	80	90	65
512	52	24			55	27		
—	36	27	MR		29	34	MR	
—	53	23			53	29		
768	63	52			73	62		
—	59	53	MR		45	61	MR	
—	63	50			73	62		

No. 120. W. 23 years. Previously healthy, especially no ear symptoms. Is pregnant, 7th month (primipara).

5 days ago (1/5 43) feeling of closing on the right ear. Next morning quite deaf on this ear. When she got up she had a severe attack of vertigo which lasted a few minutes. No vomiting. (Since, occasionally slight attacks of vertigo). Yesterday and to-day slight tinnitus in the right ear. Urine (tested a week ago): normal. Haemoglobin per cent normal.

A. d. + s.: Drums normal. Wide auditory canals.

No spontaneous nystagmus. Caloric reaction can be elicited from the right ear. v: 0/>6.00. Shout: 0/Ba.

Audiogram (5/5 43): p. 195.

	128	256	512	1024	2048	4096	8192
Air conduction. Left ear	0		0	0		15	10

Air conduction. Right ear: No hearing. Masking of the left ear with Bárány's noise apparatus.

Conclusion: Surditas dxt.
Impedance measuring (5/5 43):

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
384	14	26	72	422	18	27	88	399
512	18	31	68	350	28	29	120	351
768	35	44	72	230	39	48	69	206
1145	48	60	60	157	51	66	55	139
512	18	31						
—	8	35	MR				MR —	
—	17	31						

No. 121. W. 65 years. Formerly healthy, especially never ear symptoms. 4 months ago suddenly deaf on the left ear. At the same time and later slight vertigo. No heavier attacks of vertigo. No buzzing.

A. d. + s.: Drums normal. Wide auditory canals.
v. >5.00/0. Shout: Ba/0.

No spontaneous Nystagmus. Caloric reaction can be elicited from the left ear.

Conclusion: Surditas sin.
Impedance measuring (12/5 43):

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
384	22	36	63	297	31	32	111	314
512	39	38	103	254	44	37	121	247
768	61	83	50	101	70	88	55	87
1145	>92	110			>92	74		
512 and 768:			MR —				MR +	

Bilateral perception affections.

No. 36. M. 6 years. R. H. ward. 13193/42. Father hard hearing. Patient had scarlatina at the age of 2 without complications. Never otitis media. Mother believes that he always has been somewhat deaf. Began to talk late. Never symptoms of adenoid vegetations. W. R.: negative.
Diagnosis: Neurolabyrinthopathia acustica dxt + sin.

A. d. + s.: Drums normal. Wide auditory canals.
Rhinopharynx: No adenoid vegetations.
v: 0/0. V: >5.00/>5.00. a^1 (a): 50—55/55—65 (65). a^1 (m): 29—29/28—30 (35). R. +/+. Li: 16/25. Does not hear monochord. (Does not understand it?)
Audiogram p. 196.

Conclusion: In spite of the good bone conduction with 256 and 512 it is no doubt a perception affection. This is supported by the anamnesis, the strongly increasing loss of hearing towards the higher frequencies, the bad bone conduction here and the good Li (Li: 16 probably correct), R + and lastly the proportion between v and V.

Impedance measuring:

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
512	30	34	97	300	32	35	98	288
768	65	68	72	122	67	80	59	100
1145	78	73	84	94	86	92	73	63
512		MR —				MR —		

No. 54. W. 38 years. R. H. ward 13352/42. Previously healthy. Never before similar symptoms. No previous symptoms from the ears.

31/3 42 (3 weeks before the examination) pains behind the left ear and later anaesthesia of the left half of the head. At the same time pronounced vertigo. No ear symptoms except on one single day, when there were some pains and sensation of cold in the left ear.

The neurological examination disclosed affection of all the higher cervical roots on the left side, and some left-cranial nerves (left-sided hyposmia, decrease of the sensibility of the left part of the face including, cornea. On emotion, left facial paresis, but not by voluntary innervation. The soft palate is drawn to the right and the tongue deviates to the right).

Opthalmological examination: Paresis n. abducentis sin. l. g.

Hypaesthesia cornea sin.

A. d. + s.: Drums normal. Wide auditory canals.
v: 10.00/7.00. Li. 20/22. Ls (a) 13000/12000.
Ls. (m): 16000/14000. R: +/+.

Almost pure rotatory nystagmus towards the right. Caloric reaction can be elicited from both ears, a little less easily from the left than from the right. W. R. —.

Diagnosis: Arachnoiditis sin. Vertigo ménièriformis.

Audiogram (22/4 42): p. 196.

Conclusion: Moderate loss of hearing on the left ear, most pronounced at the higher frequencies. Slight loss of hearing on the right ear, equal in the whole range. Bone conduction bad. Lowering of Ls. Li about normal.

Perception affection.

Impedance measuring (22/4 42):

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
512	16	37	42	294	32	30	127	329
768	28	52	42	199	63	50	107	159
1145	80	116	50	49	55	39	135	208
768	27	52			58	50		
—	23	52	MR		35	46	MR	
—	27	50			56	50		

No. 63. M. 21 years. No hereditary hard hearing. Reduction of hearing from the age of 4 after pneumonia. No symptoms of otitis media at that time. 1930 acute otitis on the right ear. Treated at R. H. Pol. 2451/30. On the 13/6 30 right-sided paracentesis was performed, after which there was discharge, which ceased next day. 16/6 30 adenotomy. The opening from the paracentesis is still seen on the 15/7.

3/8 30: v: aa/0.50. R: —/+. a^1 (a): 20/?. a^1 (m): 16/25. W. R: negative.

No symptoms from the ears since then except greatly reduced hearing.

6/6 42 A. d.: Drum whitish posteriorly, otherwise normal.
A. s.: Drum normal. Auditory canals rather narrow.
v: 0,20/0,10. V: 0,50/0,40. a^1 (a): 5—6/6—8 (60). a^1 (m): 0/0.
Li: 90/55. Ls (a): 17000/17000. Ls (m): 19000/19000.
Audiogram (8/6 42): p. 196.

Conclusion: A perception affection (after an infectious disease) is suggested by the considerable loss of hearing and the bad bone conduction. This is gainsaid by: the good Ls. (with monochord) for air conduction as well as for bone conduction and corresponding to that the relatively good hearing at 8192. The patient is tabulated under perception affection because of the proportion between bone conduction and air conduction at 512 and 1024 Hz.

Impedance measuring (8/6 42):

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
384	15	27	73	405	24	29	103	360
512	23	29	100	362	30	35	91	292
768	42	49	73	199	56	61	70	146
1145	53	52	85	173	76	78	74	92
512 and 768:			MR —			MR —		

No. 65. M. 62 years. R. H. ward 13469/42. No familial loss of hearing. At the age of 20 „boil" in the right ear. Was „punctured". Can give no further information about it. Otherwise no ear symptoms except increasing deafness during the last 5—6 years. No buzzing. No vertigo.

Bilateral perception affections.

A. d. + s.: Drums whitish, otherwise normal. Wide auditory canals.
v: 0.10/0.20. V: 6.00/6.00.
Audiogram (24/6 42): p. 196.

Conclusion: Increasing loss of hearing towards the higher frequencies per air conduction. The hearing per bone conduction decreased in about the same proportion.

The diagnosis of the ear clinic: Neurolabyrinthopathia acustica dxt. + sin.

Impedance measuring (24/6 42):

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
384	15	31	56	354	25	30	100	347
512	18	37	48	292	36	33	121	293
768	42	59	53	165	54	58	73	156
1145	59	70	61	124	62	69	66	123
512	16	37			36	32		
—	10	35	MR		17	32	MR	
—	18	37			37	32		
					18	34	MR	
768	42	59			56	56		
—	25	56	MR		39	56	MR	
—	42	59			56	56		

No. 67. W. 42 years. Hardness of hearing since childhood. Was diagnosed when in hospital for scarlatina.

A. d. + s.: Drums normal. Wide auditory canals.
v: aa/0.10. V: 0.10/0.40. a^1 (a): 14/16 (60). a^1 (m): 13/11 (20).
R: +/+. Ls (a): <6000/8000. Ls (m): /10000. Li: 90/90.
W. R.: —
Audiogram (2/7 42): p. 196.

Conclusion: The proportion bone conduction/air conduction is relatively small for the low frequencies, lies at or above the fixed limit. All the other tests nevertheless speak for perception affection.

Impedance measuring (2/7 42):

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
384					17	31	63	351
512	29	26	149	379	27	34	160	348
768	43	42	96	227	43	59	55	165
1145	50	38	129	226	60	76	55	113
768	43	42			43	59		
—	27	38	MR		35	58	MR	
—	44	42			43	59		

Bilateral perception affections.

No. 70. M. 31 years. No hereditary loss of hearing. The patient has suffered from hardness of hearing since the age of 17—18. At this age he worked in a loud noise about 1/2 year. Not before or after. The hearing has since then been steadily decreasing. Steady pulsating buzzing, noticed in the middle of the head.

A. d. + s.: Drums normal.

v: 0.10/0. V: 1.00/. V: Ba/0.

Audiogram (6/7 42): p. 196.

Masking of the right ear with Bárány's noise apparatus: no hearing on the left ear. Caloric reaction elicited normally from the left ear.

Conclusion: Anamnesis, increasing loss of hearing towards the higher frequencies per air conduction and the poor bone conduction speak for perception affection. So does also the total loss of hearing on the left ear.

Impedance measuring (6/7 42):

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
384	15	30	59	365	45	45	90	210
512	22	33	73	322	Quite indistinct minimum			
768	37	55	51	181	-	-		-
1145	52	74	48	122	58	38	145	200

MR not tested.

No. 71. W. 51 years. In May 42 „Frontal sinusitis" treated with suction. Subfebrile about 1 month. The symptoms disappeared about the 1st June. Never before ear symptoms.

In the morning of 2/7 42 (5 days before the 1st examination) suddenly whistling on the left ear. Noticed, during telephoning, that the hearing on the left ear was reduced. In the course of a few hours total deafness on the left ear. The whistling ceased after 2 days. One day no sound. After this seething and singing which persist. No vertigo.

A. d. + s.: Drums normal.

7/7 42 v: >5.00/0. Shout: Ba/0. Caloric reaction can be elicited from the left ear. No spontaneous nystagmus.

Audiogram (7/7 42): p. 196 (a).

Masking of the right ear with Bárány's noise apparatus: no hearing on the left ear.

Conclusion: Sudden deafness on the left ear. Slight loss of hearing on the right ear. (Cause?).

Impedance measuring (7/7 42):

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
384	15	30	59	365	14	29	59	379
512	24	32	86	329	23	32	82	331
768	43	57	58	170	50	56	70	166
1145	76	80	71	90	83	80	81	79
512					22	32		
—		MR	—		15	32	MR	
—					23	32		
768					51	57		
—		MR	—		31	53	MR	
—					49	56		

28/7 42: Hearing on the left ear, improved. Buzzing decreased.
Audiogram (28/7 42): p. 196 (b).
Impedance measuring (28/7 42):

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
384					15	29	64	378
512	25	34	80	310	25	32	89	327
768	42	60	51	162	48	55	70	171
1145					80	74	84	90
512	25	34						
—	15	37	MR					
—	25	34						
768	42	60						
—	25	57	MR					
—	42	60						

27/8 42: No symptoms any more.

Audiogram (27/8 42):	128	256	512	1024	2048	4096	8192
Air conduction. Left ear.	15	15	20	15	15	15	25

Impedance measuring (27/8 42):

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
384					15	28	67	390
512					24	30	97	349
768					48	53	74	177
1145					78	72	84	96

No. 106. W. 57 years. R. H. Pol. 5502/42. Treated in Dept. A for myxedema and degeneratio myocardii. No familial hard hearing. During the last 1/2 year increasing hardness of hearing on both ears. At the same time fatigue, function dyspnea, and depression. No buzzing or vertigo. Never ear aches or discharge. The hearing previously good.

A. d. + s.: Drums normal. Auditory canals fairly wide.
v: 0/0. V: 2.00/2.00 (Ba).
Audiogram (10/12 42): p. 197.

Conclusion: The hearing loss is steadily increasing towards the high frequencies. Bone conduction decreased in the same proportion as air conduction.

Impedance measuring (10/12 42):

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
384	29	30	117	337	31	28	139	350
512	39	34	125	279	47	35	139	248
768	74	84	65	88	79	87	68	79
1145	79	65	96	101	84	77	86	80
768					79	87		
—		MR +			68	84	MR	
—					79	88		

No. 107. Boy, 8 years. The maternal grandfather suffered from hardness of hearing. Otherwise no deafness in the family. The mother cannot state when his hardness of hearing began, he has possibly always been hard hearing. Never seriously ill. In addition to the usual children's diseases he has only had scarlatina. Never earache or discharge. Never symptoms of adenoid vegetations.

A. d. + s.: Drums normal. Fairly narrow auditory canals.
Rhinopharynx: No adenoid vegetations.
v: 0.05/0.05. V: 1.00/1.00.
Audiogram (20/1 43): p. 197.

Conclusion: The hearing per air conduction better at the lower than at the higher frequencies. Poor bone conduction. Anamnesis as well as examination suggestive of perception affection.

Impedance measuring (20/1 43):

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
512	36	25	189	357	43	22	254	333
768	44	45	88	211	51	40	123	216
768	44	45			53	42		
—	33	44	MR		37	36	MR	
—					55	41		

Bilateral perception affections.

MÉNIÈRE'S SYNDROME

Unilateral impairment of hearing.

No. 28. M. 44 years. R. H. ward 13140/41. Since 1934 attacks of vertigo and constant buzzing on the right ear. Gradually hard hearing on this ear. 1938 treated at the hospital with decreased supply of fluid and light. After this no attacks during 2 years.

1940 repeated attacks of 1/2—3/4 hour's duration associated with vomiting. During the last year very frequent brief attacks (1—2 min.). No protracted attacks.

Apart from slight diabetes healthy.

A. d. + s.: Drums normal. Wide auditory canals.
v: 0.20—6.00/>12.00 (48—27). V: 10.00/ a^1 (a): 18/50 (92).
a^1 (m): 10/13 (33). R. +/+. Li: 60/16. Ls (a): 12000/13000.
Ls (m): 16000/17000.

No spontaneous nystagmus. Caloric reaction: normal.

Opthalmological and neurological examinations: Nothing abnormal. W. R. negative.

Patient had several short attacks of vertigo in the ward. Once nystagmus towards the left was noticed.

Diagnosis: Morbus Ménière.

Audiogram (8/12 41) and Fowler's test: p. 197.

Conclusion: Considerable elevation of Li. corresponding to the uniform reduction of hearing for the deeper and higher tones in the audiogram. Ls. (a) 12000, about the same on the normal and the affected ear. The high sounds are heard better with whisper (27) than the deep sounds (48) (danish). Fowler's test: Perception affection.

Impedance measuring (11/12 and 12/12 41):

	Right ear					Left ear				
	a	v	w	q		a	v	w	q	
384	24	28	109	371		25	31	95	337	
512	31	30	116	337		32	44	65	233	
768	45	55	65	175		47	72	44	129	
1145	70	73	72	107		81	120	50	46	
512	18	28	81	385	MR	27	42	59	250	MR

The measurings during the single days:

	11/12 41				12/12 41			
	Right ear		Left ear		Right ear		Left ear	
	a	v	a	v	a	v	a	v
384	24	28	22	38			28	25
512	30	30	31	44	36	31	35	43
768	48	54	48	74	43	57	46	70
1145	76	73	80	133	62	74	82	108

No. 37. W. 55 years. R. H. ward 13203/42. Migraine since youth. Otherwise healthy.

Since May 1935 5 violent attacks of vertigo, and numerous minor attacks. Morover sensation of unsteadiness. At the same time as the first attack buzzing in the right ear, has persisted since then, and the hearing on this ear has decreased.

A. d. + s.: Drums normal.
v: 0.05/>5.00. V: 0.20/Ba. a^1 (a): 12/44. a^1 (m): /15.
R: +/+. Li. 55/16. Ls (a): 12000 (Ba)/12000. Ls (m): /16000.
No spontaneous nystagmus. Caloric reaction is elicited somewhat more slowly from the right ear and is at the same time somewhat weaker than the nystagmus elicited from the left ear.

During the hospital stay vertigo with nystagmus towards the right.

Eye examination: Cataracta zonularis sin. — Cataracta incip. dxt.

Neurological examination: Morbus Ménièri — Migraine.

Audiogram (22/1 42) and Fowler's test: p. 197.

Conclusion: The audiogram (air conduction) of the right ear shows a very considerable loss of hearing, least pronounced for the highest frequencies. Corresponding to this Ls (a) is fairly good (12000 with masking of the left ear). Li. is elevated. Whilst these teste sooner are suggestive of a conduction affection, Fowler's test shows that there is a question of perception affection, as there is a marked regression for all the frequencies used.

Impedance measuring (22/1 42):

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
384	24	27	117	384				
512	36	28	158	331	31	24	182	393
768	55	52	89	170	50	39	125	223
1145	62	56	90	149	51	46	99	195
512		MR +			11	26	MR	
					30	22		

No. 68. M. 62 years. R. H. ward 13488/42. 30 years ago homogeneous hardness of hearing on both ears. Was for about 1 year successfully treated with catheterization of the tuba. Otherwise no ear diseases.

During the last 5—6 years the hearing on the right ear has decreased. During about 3 years pulsating buzzing in the right ear. 1½ years ago an attack of vertigo. During the last 10 days 2 severe attacks of vertigo.

A. d. + s.: Drums normal. Wide auditory canals.
v: aa/Ba. v: />6.00. V: 0.20/Ba.
a^1 (a): is not heard/100. a^1 (m): 30/43. R: /+.
Li: >150/24. Ls (a): 10000/13000. Ls (m): 17000/17000.
Caloric reaction normal.

Ménière's syndrome.

Neurological examination: no signs of an organic nerve disease.
W. R. negative.

During the stay in the ward (1/7 42) an attack of vertigo with strong spontaneous nystagmus towards the left. After about half an hour it changed to the right.

Diagnosis: Morbus Ménière.

Audiogram (1/7 42 after the attack of vertigo) and Fowler's test (3/7 42) p. 197.

Conclusion: The loss of hearing is more pronounced for the high than for the low frequencies. Just as for the preceding patient a diagnosis cannot be made with the help of the usual hearing tests.

Fowler's test shows marked regression for all frequencies (least for 4096) and points thus to a perception affection.

Impedance measuring (2/7 42):

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
384	15	34	47	323	16	31	60	353
512	24	37	66	286	25	36	72	293
768	42	59	53	165	40	57	53	172
1145	40	73	35	129	51	72	48	126
512	25	37			26	37		
—	12	41	MR		12	39	MR	
—	24	39			24	36		
768	42	60			39	57		
—	19	59	MR		19	58	MR	
—	42	60			40	57		

No. 80. M. 59 years. R. H. ward 13648/42. During recent years loss of hearing on the left ear. Now and then buzzing.

During the last 7—8 months attacks of vertigo. Once only nausea. No vomiting. Hearing and buzzing unchanged during the attacks. Never earache or discharge.

A. d. + s.: Drums somewhat whitish, otherwise normal.
v: 2.00/0. V: >8.00/0.80 (Ba). a^1 (a): 91/16 (60).
a^1 (m): 20/14 (25). R: +/—. Li: 20/90.
Ls (a) 12000/8000. Ls (m): 13500/13500.

On admission spontaneous nystagmus to the left.

Later, when there was no spontaneous nystagmus, a normal caloric reaction could be elicited from the right ear, only a very weak reaction from the left ear.

Neurological examination: Nothing reliably abnormal.

Diagnosis: Morbus Ménière.

Audiogram (20/8 42) and Fowler's test: p. 197.

Conclusion: The audiogram (air conduction) of the left ear shows a very considerable loss of hearing, most pronounced at the high frequencies. Some lowering of Ls (monochord). Fowler's test: Perception affection (over-recruitment).

Impedance measuring (31/8 42):

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
384	23	29	98	363	20	27	87	400
512	31	32	111	314	27	30	108	342
768	57	59	76	150	45	51	73	187
1145	71	70	77	110	57	58	78	152
512					28	30		
—		MR (+)			20	32	MR	
—					26	30		
768					45	50		
—		MR +			31	52	MR	
—					45	51		

MÉNIÈRE'S SYNDROME

Bilateral impairment of hearing.

No. 32. M. 53 years. R. H. ward 13194/42. Previously healthy, especially never discharge from the ears.

Since August 1940 attacks of vertigo with intervals of days or weeks, now and then associated with vomiting. The attacks begin with buzzing in the right ear. The hearing of the right ear has gradually decreased.

A. d.: Drum shows somewhat fibrous changes in the posterior half.
A. s.: Drum normal. Wide auditory canals.
v: 0.50/>5.00. a^1 (a): 32/65. a^1 (m): 15/28. R. +/+.
Li: 24/16. Ls (a): 11000/12000. Ls (m): 14000/14000.

Spontaneous nystagmus towards the left. During several attacks in the ward increased nystagmus towards the same side.

Caloric reaction: 2) 45" (+ 7°)/ 1) 37" (— 7°). 2) weaker than 1). Eye examination: Hypermetropia. — Amblyopia congenita dxt. — Cataracta.

Neurological examination: Patellar reflexes cannot be elicited, otherwise nothing reliably abnormal.

Spinal fluid: normal conditions.

W. R. (in blood and spinal fluid) negative. Blood Pressure: 165/105.

Diagnosis: Morbus Ménière.

Audiogram (12/1 42) and Fowler's test (7/1 42): p. 197.

Conclusion: Audiogram (air conduction) shows a moderate loss of hearing on the right ear, equal for deep and high frequencies. On the left ear a slight

impairment for 256—512 Hz. Li. about normal. Ls slightly lowered for both ears, in the same proportion per air conduction and bone conduction.

Fowler's test: Perception affection (apart from 256 Hz., where there is no regression).

Impedance measuring (12/1 42):

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
512	29	27	140	367	not examined			
768	39	46	74	215	-	-		
1145	62	55	93	151	-	-		

No. 53. W. 48 years. R. H. ward 13369/42. Since about 1931 periodical attacks of vertigo. The attacks last 1—3 hours, sometimes 8—9 hours. Periodically 2—3 times a week. Sometimes no attacks for from 6 to 18 months. The attacks occur suddenly. May occur at any time of day or night. Gyratoric vertigo with a falling tendency to the right. Now and then nausea and vomiting.

Since the commencement of the attacks 1931 reduction of hearing on the right ear. Constant pressure and buzzing on the right ear, and buzzing in the left ear. Never discharge or earache.

A. d. + s.: Drums dull, slightly fibrous.
v: 0.10/>5.00. V: 1.00/5.00 (Ba). a^1 (a): 20/60.
a^1 (m): 30/15. R: —/+. Li: 90/24. Ls (a): 6000/14000.
Ls (m): 14000/13000.

No spontaneous nystagmus. The caloric reaction can be elicited equally from both ears. During the stay in hospital several attacks of vertigo with nystagmus towards the right.

Neurological examination: No signs of any organic nerve affection.

Diagnosis: Morbus Ménière.

Audiogram (18/3 42) and Fowler's test: p. 197.

Conclusion: Audiogram: (air conduction). Moderate loss of hearing on the right ear, most pronounced at the high frequencies. Slight loss of hearing on the left ear. On the right ear some lowering of Ls (besides some elevation of Li).

Fowler's test: Perception affection (over-recruitment), apart from 128 Hz., where there is no regression.

Impedance measuring (22/4 43):

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
512	25	37	68	285	12	38	30	288
768	45	64	50	149	31	55	42	185
1145	63	80	55	103	30	66	30	150
512 and 768:			MR +				MR —	

No. 74. W. 37 years. R. H. ward 13580/42. No ear diseases in the family. At the age of 8 the patient had bilateral otitis media. Discharge for a short time. The hearing usually good.

Since the age of about 9 she has been suffering from attacks of headache, vertigo, vomiting and hammering and pulsation in both ears. The attacks occur a couple of times a year. They last from 8 days to 3 months. The patient must stay in bed the whole time during the attack.

Never loss of consciousness, visual disturbances, spasms or pareses.

The patient has been treated in hospital several times, inter alia with thirst cure and carbon arc light, sometimes with some effect.

A. d. + s.: Drums normal (slightly cicatrized?)
v: 1.00/0.50. V: 4.00/3.00.

In dorsal recumbent posture a fine horizontal-rotatory nystagmus is seen. It becomes rather weaker in right and left lateral recumbent position. Caloric reaction can be elicited equally and normally from both ears.

W. R. (in blood and spinal fluid) negative.

Neurological examination: No signs of any organic nerve affection.

Audiogram (24/8 42): p. 198.

Conclusion: The audiogram shows that there is a question of perception affection (the hearing loss most pronounced at the high frequencies, bone conduction decreased in about the same proportion as air conduction).

Diagnosis: Vertigo.

Morbus Ménière atypica.

Impedance measuring (24/8 42):

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
512	18	37	48	292	23	35	70	303
768	31	56	41	182	47	63	54	150
1145	59	81	49	105	82	72	90	88
512 and 768:	MR +				MR +			

No. 79. W. 64 years. R. H. ward 13692/42. No familial dispositions, especially no deafness.

At the age of 38 rheumatic fever with cardiac symptoms, which disappeared gradually. During recent years she has again had palpitations and function dyspnea. Menopause at the age of 53, without special discomforts.

Never before ear symptoms.

During the last 9 years she has suffered from attacks of giddiness associated with nausea and vomiting. The attacks occur at irregular intervals of days or weeks, both day and night, always very suddenly. During the attacks there is buzzing in the right ear and right-sided hard hearing. The attacks last from 10 minutes to several hours. Gradual reduction in hearing on the right ear also between the attacks.

Ménière's syndrome.

During the attacks some frontal headache, else not.

A. d. + s.: Ear drums normal.

v: 0/0.50. V: 0.10/3.00. (Ba.).

In dorsal recumbent posture a fairly slow nystagmus towards the left is seen. It increases in lateral recumbent position, particularly in the left position. (No subjective giddiness). In the intervals between the attacks a faint caloric reaction can be elicited from the right ear, normal reaction from the left ear. During attacks no reaction is obtained from the right ear. From the left ear the nystagmus can be checked. Nystagmus towards the right during the attack.

The remaining examination disclosed nothing abnormal. W. R. negative.

Neurological examination: No signs of cerebellopontine angle tumor. Basal arachnoiditis?

Diagnosis: Ménière's disease.

a^1 (a): 5/12 (60). a^1 (m): 5/5 (25). Li: 50/24. Ls (a): 6000/12000.

Ls (m): 13000/13000.

Audiogram (31/8 42): p. 198.

Conclusion: The audiogram indicates perception affection, the normal Ls (m) speaking against it however.

Impedance measuring (31/8 42):

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
384	28	25	154	395	25	23	160	434
512	36	29	150	324	32	26	163	367
768	64	57	91	143	57	50	97	172
1145	90	55	122	70	67	62	85	129
512			MR +				MR +	
768	66	57						
—	51	66	MR				MR +	
—	66	59						

No. 94. W. 62 years. Previously healthy, especially no ear diseases. For about 3 years attacks of giddiness at intervals of weeks or months. At first hard hearing and buzzing in the right ear during the attacks. Gradually her hearing has decreased on both ears.

A. d. + s.: Ear drums normal.

v: 0.10/0.50. V: 0.50/4.00. R: +/+. Li: 90/24.

Ls (a): <6000/8000. Ls (m): 6000/6000.

No spontaneous nystagmus. Caloric reaction normal.

Diagnosis: Morbus Ménière.

Audiogram (15/9 42): p. 198.

Conclusion: Loss of hearing per air conduction most marked for the high

frequencies. Bad bone conduction. Lowering of Ls. both per air conduction and bone conduction. Perception affection.

Impedance measuring (15/9 42):

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
384	29	27	140	367	21	25	119	420
512	39	32	137	291	30	27	144	364
768	69	68	77	117	51	48	92	189
1145	88	52	127	78	75	56	109	120
512 and 768:			MR +				MR +	

No. 98. W. 43 years. R. H. ward 13780/42. Attack of giddiness 4 years ago. At the same time bilateral ear buzzing. Gradually hard hearing developed, first on the right, later on the left side too. During the subsequent years attacks of giddiness at intervals of from 6 to 12 months. In the last 3 weeks prior to admission 5 attacks. Never earache or discharge.

A. d. + s.: Ear drums somewhat dull, slightly sclerosed. Large auditory canals.

v: aa/0.05. V: 4.00/6.00 (Ba). a^1 (a): 22/32 (115).
a^1 (m): 0/0 (35). R: +/+. Li: 90/80. Ls (a): 11500/12000.
Ls (m): 14000/17500.

Nystagmus towards the left, when lying on the left side, later in dorsal recumbent posture too.

Caloric reaction elicited equally from the two sides.

Neurological examination: No signs of organic nerve disease.

W. R. negative.

Audiogram (3/11 42): p. 198.

Conclusion: The patient is tabulated with the perception affections on account of the proportion between bone conduction and air conduction. The remaining examinations rather speak against perception affection (elevation of Li, the good Ls per bone conduction).

Impedance measuring (16/11 42):

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
384	27	37	74	282	28	39	70	267
512	42	39	106	243	44	44	91	216
768	64	67	72	124	67	81	58	99
1145	66	84	55	96	81	88	70	75
768	69	69			67	81		
—	48	70	MR		48	82	MR	
—	64	69			69	84		

Ménière's syndrome.

Uncertain diagnoses.

No. 73. W. 50 years. No familial disposition. Never otitis media. For some months reduction of hearing on left ear. During the same period a sensation as of a valve before that ear. Unsuccessfully treated with tuba catheterization.

A. d. + s.: Ear drums normal. v: >6.00/1.00.
Audiogram (16/7 42) and Fowler's test: p. 198.
Impedance measuring (16/7 42):

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
384	7	28	30	399	7	21	52	534
512	10	31	37	359	4	27	10	416
768	25	42	55	251	10	36	28	306
1145	23	54	32	193	19	44	37	244
512 and 768: MR —							MR —	

No. 112. W. 34 years. About 2 years ago, suffering from a cold, she on telephoning became aware of reduction of hearing on her right ear. No pains. No sensation of valve or occlusion on that ear, on the other hand buzzing. Since then her hearing has not changed. Constant buzzing.

Never discharge. No symptoms from the left ear. Neither nose nor throat symptoms now.

A. d. + s.: Ear drums normal. Large auditory canals.
v: 0.50/>5.00. Weber: Lateralization towards the left.
Audiogram (11/2 43) and Fowler's test: p. 198.
Impedance measuring (11/2 43):

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
384	28	35	85	295	30	30	120	334
512	37	41	86	243	40	35	121	269
768	69	86	56	90	61	60	80	142
1145	80	90	67	74	73	78	70	96
512	22	42	MR				MR —	
—	37	42						
768	46	74	MR				MR —	
—	70	89						

No. 113. W. 57 years. About 13 years old she incurred pains in the left ear, persisting for several months. No discharge. Since then reduction of hearing on that ear. No buzzing. No symptoms from the right ear. Never symptoms of adenoid vegetations.

A. d. + s.: Ear drums normal.
Li: 18/26. Ls (a): 14000/11000. Ls (m): 16000/15000.
Audiogram (19/2 43) and Fowler's test: p. 198.
Impedance measuring (19/2 43):

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
512	40	21	262	362	49	22	264	288
768	59	32	182	210	62	40	142	183

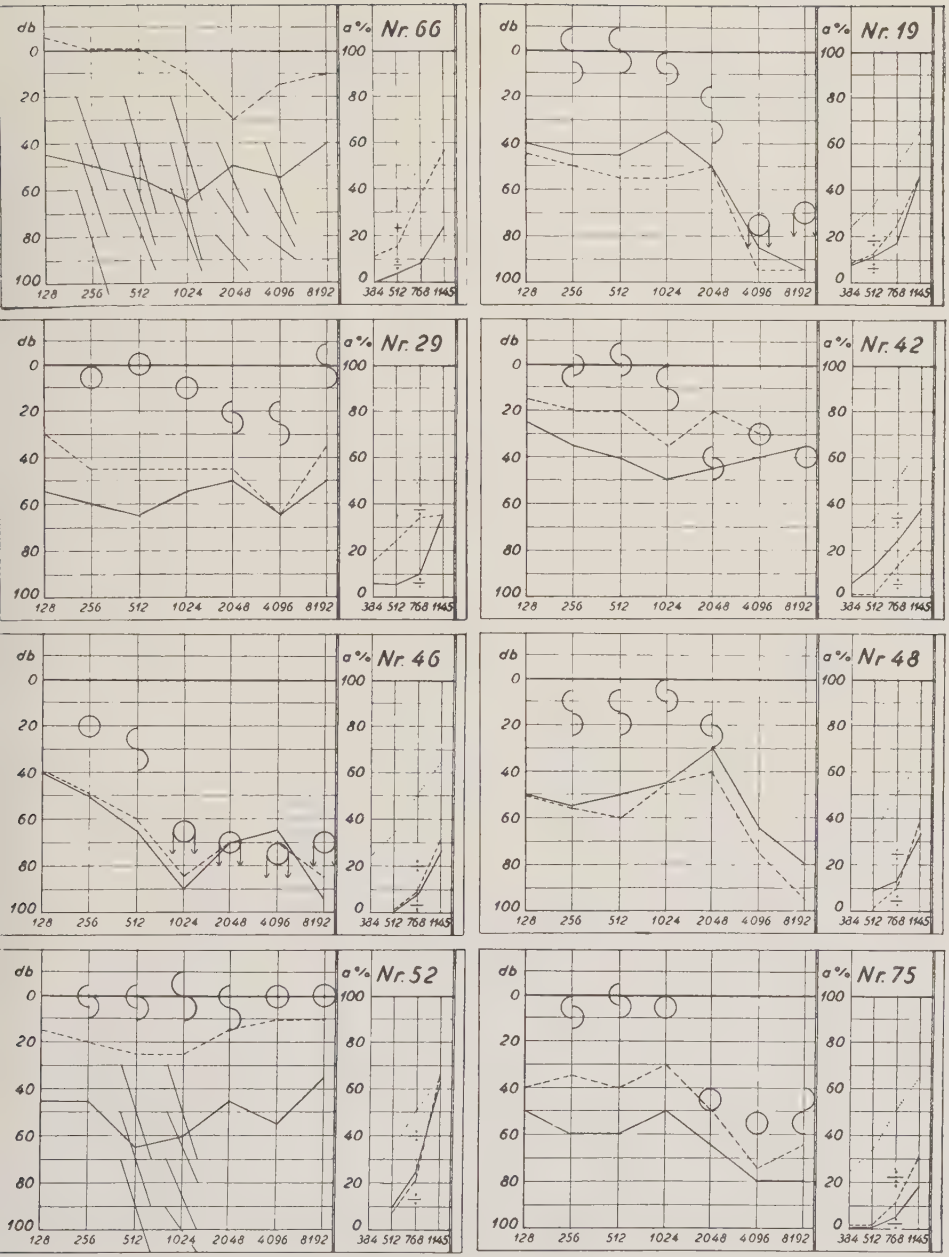
512 and 768: MR + MR +

No. 100. M., 50 years. R. H. ward 13770/42. About 1/8 42 the patient incurred giddiness which has persisted incessantly since then. No ear symptoms. Never earache or discharge.

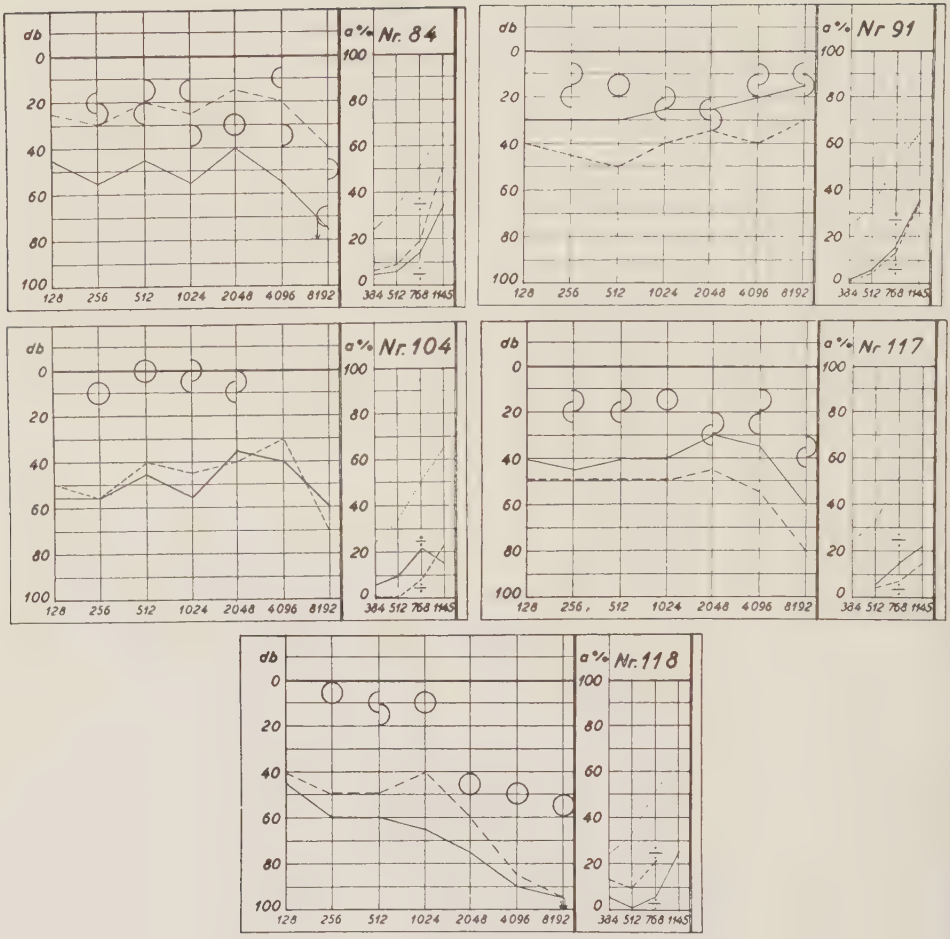
A. d. + s.: Ear drums normal.
v: 0.50/0.50. a^1 (a): 65/70 (90). a^1 (m): 18-25/10 (45). R: +/+.
Li: 16/16. Ls (a): 12000/12000. Ls (m): 14000/13000.
No spontaneous nystagmus. Reduced caloric reaction on the right ear, strong reaction on the left ear.
Neurological examination: Slighter basal arachnoiditis with elective vestibular affection.
Diagnosis: Neuritis ram. vestibularis sin. — Arachnoiditis (Mb. Ménière atypica).
Audiogram (10/10 42) p. 198.
Impedance measuring (21/11 42):

	Right ear				Left ear			
	a	v	w	q	a	v	w	q
384	15	38	38	286	18	38	46	284
512	24	42	52	252	28	42	61	248
768	46	66	49	143	45	70	43	134
1145	61	81	51	103	70	91	52	82
512	24	43			28	42		
—	12	44	MR		15	43	MR	
—	24	42			28	42		
768	59	81			72	92		
—	44	88	MR		44	90	MR	
—	62	81			70	91		

Uncertain diagnoses.



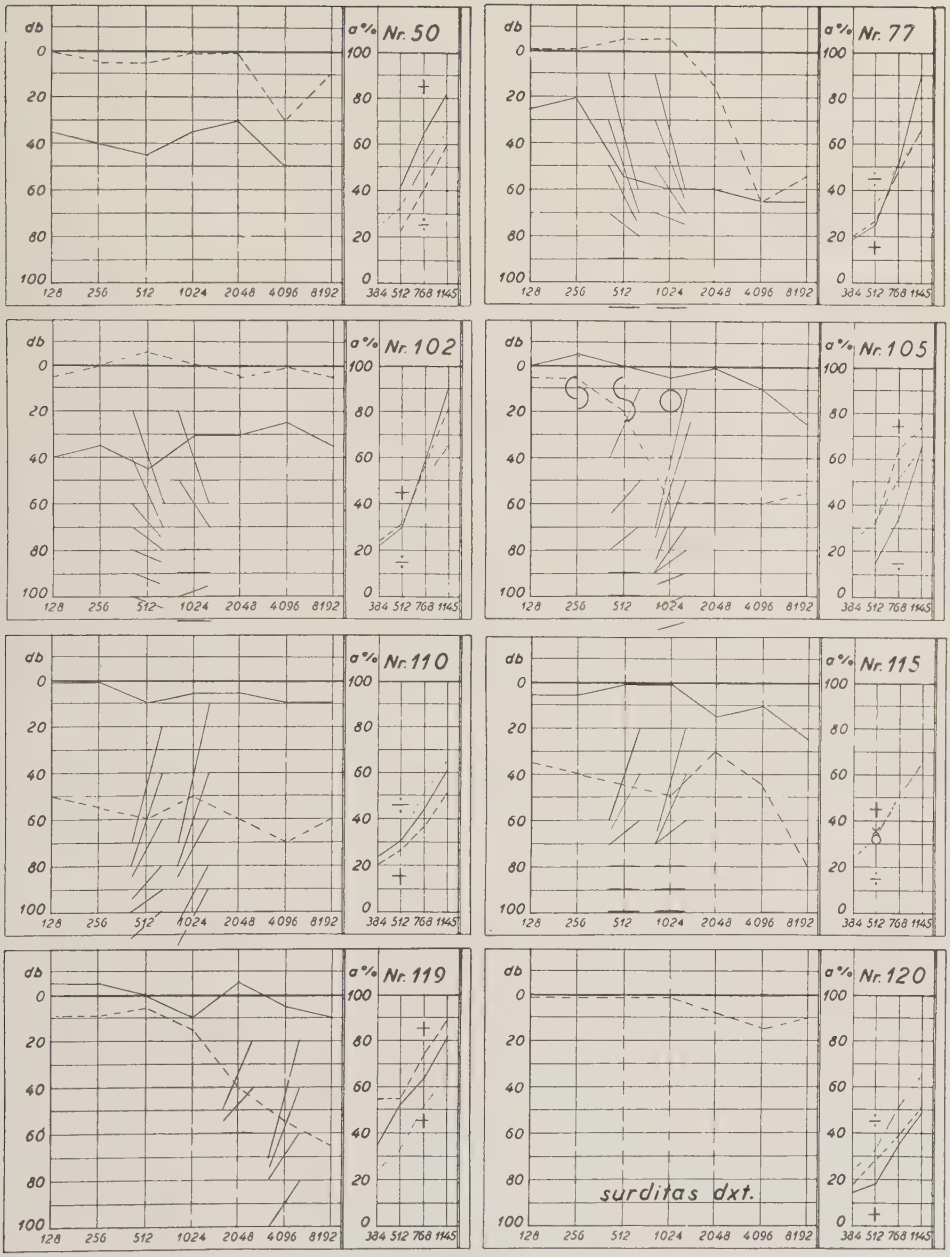
Conduction affections.
Explanation of signatures see p. 194.



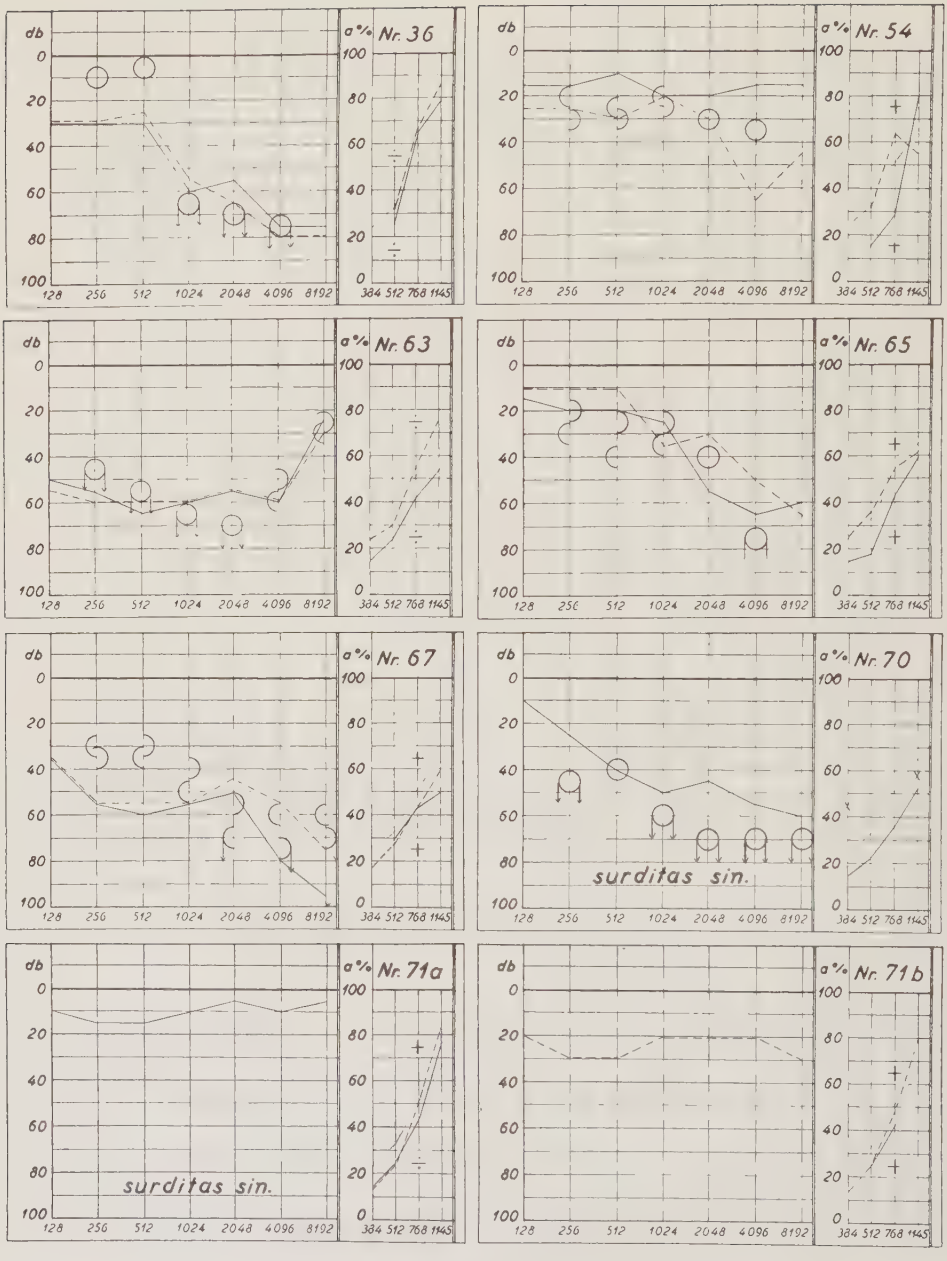
Conduction affections.

Explanation of the signatures:

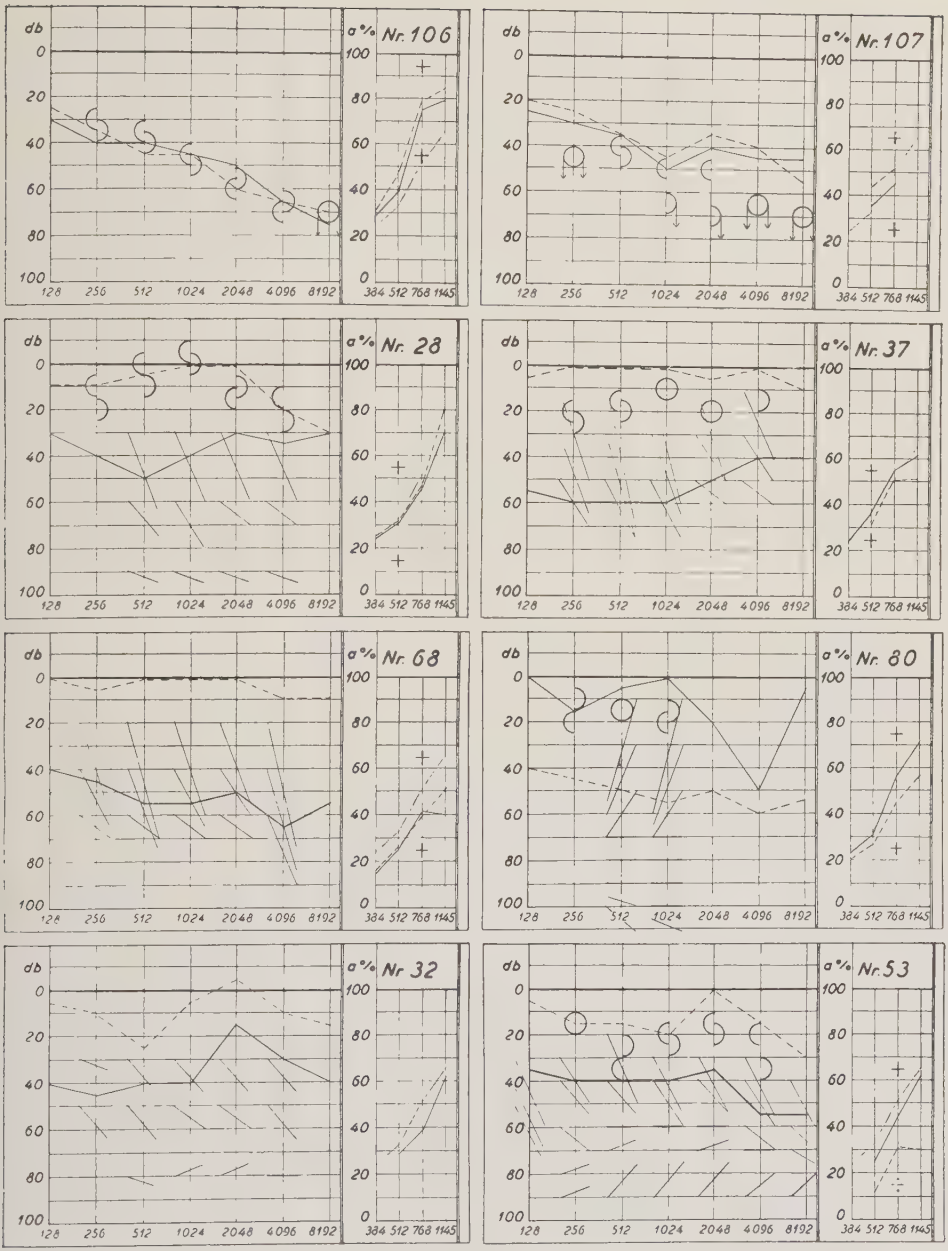
——————— Air conduction (absorption) right ear.
— — — — Air conduction (absorption) left ear.
ɔ Bone conduction right ear.
c Bone conduction left ear.
..... Mean value of Abs. for normal ears.
+ Muscle contraction can be elicited on the ear in question.
÷ Muscle contraction cannot be elicited on the ear in question.



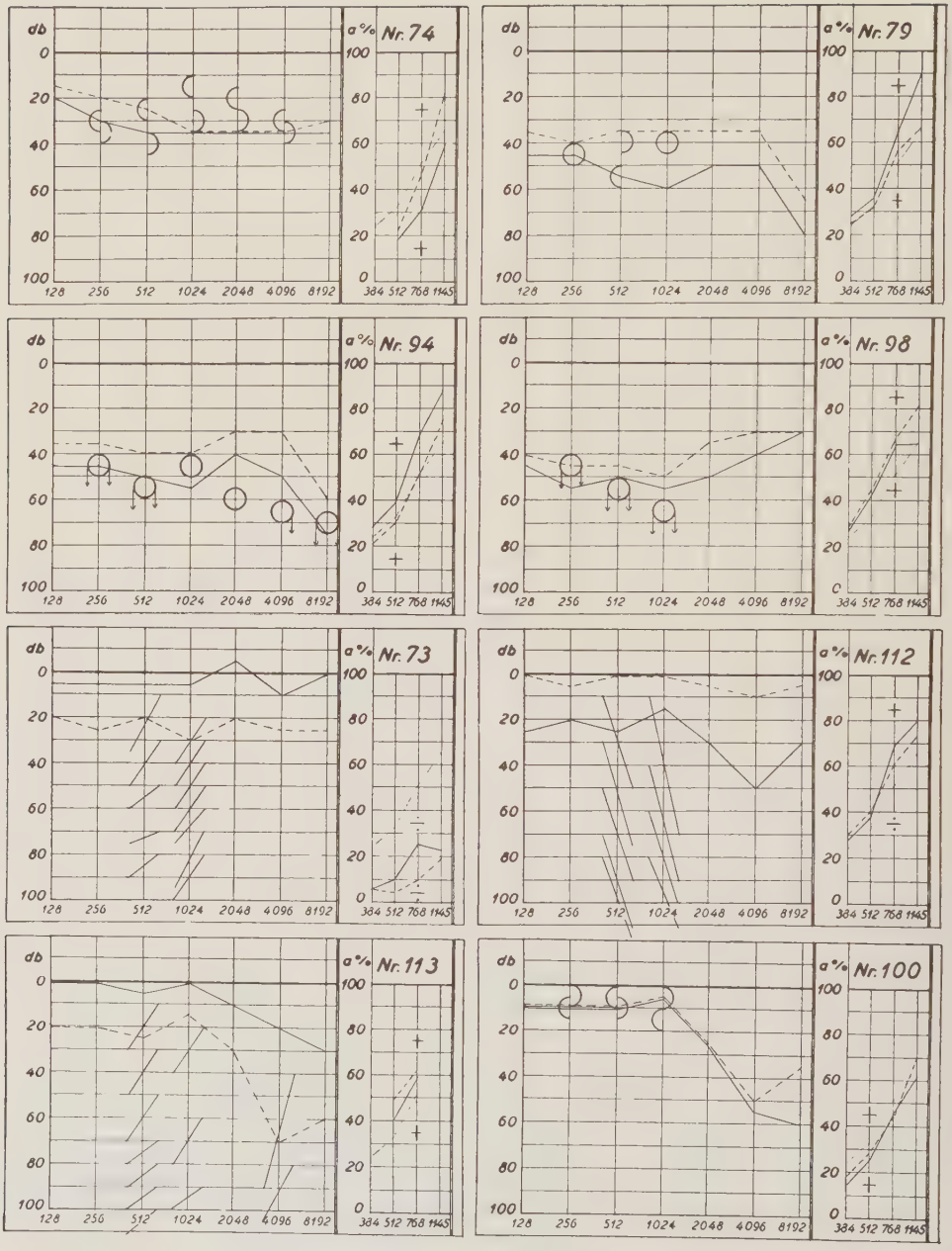
Unilateral perception affections.



Bilateral perception affections.



Bilateral perception affections.
Ménière's syndrome.



Ménière's syndrome.
Uncertain diagnoses.

IX. THE IMPEDANCE IN CONDUCTION AFFECTIONS ASSOCIATED WITH NORMAL EAR DRUMS

Remarks on the functional tests and the diagnoses.

There were examined 2 patients with unilateral and 12 with bilateral conduction affections. In the conclusion of the case reports was mentioned what was suggestive of a conduction affection. On the results of the function tests and the diagnoses the following may be added.

Of the *unilateral* cases No. 21 is undoubtedly a conduction affection. No. 66 is somewhat more doubtful, but we think that the facts stated in the conclusion, incl: Fowler's test, justify the placing.

The *bilateral* are, as stated, mainly classified in regard to the proportion bone conduction/air conduction. As seen in the Table 13 it was $<2/3$ in 8 patients (Nos: 19—29—42—48—75 —104—117—118). Nos. 19, 75 and 118 show a distinct loss of hearing for the high frequencies. In Nos. 48, 104, and 117 the curve for 8192 drops but is otherwise horizontal (117) or it drops towards the lower frequencies (48 and 104). *Crowe* and *Guild* having shown that such curves may also be obtained for conduction affections, and that a loss of hearing, most pronounced at the high frequencies, may be produced (*Lüscher* 1939) by loading the drum, it can hardly be said that the air conduction curve in the mentioned cases speaks against a conduction affection. At any rate the normal or almost normal bone conduction for the low and middle frequencies (19, 75, 104, and 118) shows that these are conduction affections.

In Nos. 48 and 117 bone conduction is somewhat reduced, but the proportion bone conduction/air conduction is still

$< 2/3$, they are therfore regarded as conduction affections, to which also the tests with the tuning-fork and the monochord examination point.

Two cases (46 and 91) could not be classified after bone conduction/air conduction as mentioned on page 156. (Classification of the material). No. 46. For 512 the proportion bone conduction/air conduction for the one ear lies just above and for the other just below the boundary line. For 1024 both ears are among the perception affections.

For reasons mentioned in the case reports a conduction affection is presumed for the deep frequencies, but this seems to be one of the rather few patients where there is reason to assume a combined hardness of hearing.

In No. 91 the proportion bone conduction/air conduction is completely as in the previous case, for 512 both ears lie on the boundary-line, for 1024 the proportion is about 1. But there is a fairly great difference in the hearing on the two ears. As mentioned in the report, the form of the air conduction curve is suggestive of a conduction affection. So are the monochord and tuning fork tests too.

There remain two cases (52 and 84) which, because of the great difference in the hearing on the 2 ears, cannot be classified after the proportion between bone conduction/air conduction. The report shows that No. 52 is a sure conduction affection. No. 84 is the most uncertain, but the determination of the upper and lower limit is most suggestive of a conduction affection. It is not possible to make a diagnosis on the basis of the audiogram. *The Diagnoses.* In most cases there probably is a question of otosclerosis. The diagnosis has been made tentatively except in 7 cases where there is a familial hardness of hearing.

The impedance in conduction affections with normal ear drums.

The absorption. In Fig. 22 the Abs. and Phase curves are plotted for all the 26 hard hearing ears. It is immediately seen that the Abs.-curves keep at a much lower level than the corresponding normal curves, for with the exception of 3 curves they lie fully outside the *average dispersion area of these.* The

one curve which lies high corresponds to the Abs. for No. 29 left ear. It lies within the normal dispersion area for 384 and 512 Hz., at the lower border for 768, but low for 1145 Hz. Abs. for the right ear is very low.

The 2 other curves correspond to the right and left ear of

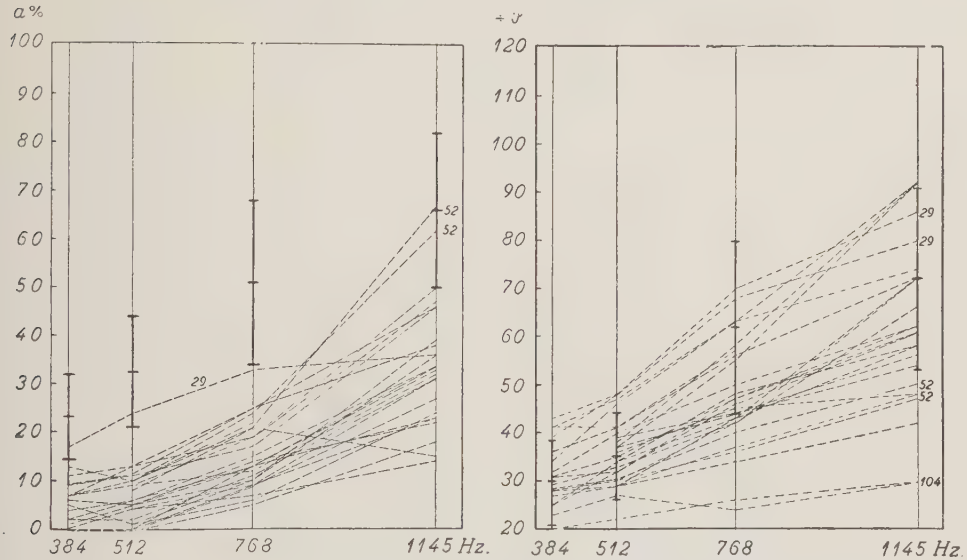


Fig. 22. Conduction affections with normal ear drums. (Absorption and Phase curves). (The central point of the full lines parallel to the ordinate shows the mean value, their terminal points, the standard deviation of the ears of the normal material).

No. 52. The Abs. is low for the three lowest frequencies, high only for 1145 Hz. That corresponds to the hearing being best at the high frequencies, but the high Abs. is possibly only an expression of the greater uncertainty at this frequency.

With the exception of these 3 ears a low Abs. for all frequencies is thus found for all ears, which after the function tests have been classified as conduction affections, i. e., for 15 ears out of 16 classified according to the proportion bone conduction/air conduction and for 6 ears out of 8, where the diagnosis has been made more or less reliably after the other function tests. Finally there is a low Abs. on the two hard-hearing ears of the two patients with unilateral hard hearing.

On the whole accordance was found between the Abs. and the function tests in 23 out of 26 deafened ears of 14 patients.

Of the greatest interest is the Abs. of the ears with most uncertain diagnosis.

The two patients with unilateral hardness of hearing.

There is here a striking difference between the Abs. of the affected and that of the normal ear. For 512 and 768 Hz. the Abs. on the normal ear is 3 (No. 21) or 4 times (No. 66) as great as of the affected ear.

On the normal ear of No. 21 the Abs. is normal. On the normally hearing ear of No. 66 it is for the two lowest frequencies somewhat low, for the two highest normal. (As an explanation of the low Abs. it might be assumed that the patient has an otosclerosis, which also the familial hard hearing, the anamnesis, and the tests might indicate. The otosclerotic changes would then be fairly advanced on the right ear. On the other ear they have just commenced and have only given a decrease of the Abs. for the lower frequencies, but not yet a loss of hearing. A later examination of such a patient would of course be of considerable interest).

Cases with bilateral loss of hearing. The Abs. of No. 46 has been examined twice. The first time we found a fairly low Abs. for the right ear and a very low Abs. for the left ear. A week later a very low Abs. on both ears.

No difference of the hearing was found. The differences in the Abs. may perhaps be due to the first examination not having been sufficiently careful in avoiding the sources of error, especially at the examination of the right ear, and that this is the cause of the higher Abs. For the left ear there is no great difference. It must generally be assumed that the lowest Abs. measured are the correct ones — this has previously been mentioned — only these curves are plotted in the diagram.

No. 52. with a sure otosclerosis has been mentioned. There is a high Abs. for 1145 Hz. (see the Abs. diagram). For the other frequencies the Abs. is low and equal for both ears – in spite of the considerable difference of hearing. No. 84, where the diagnosis is very uncertain, on both ears has a very low Abs. which speaks for a conduction affection. Here

too a relatively high Abs. is found on the one ear for 1145 Hz.

No. 91 could not be classified after the proportion bone conduction/air conduction. There is a rather big difference in the hearing on the 2 ears, but the function tests speak for a conduction affection. The very low Abs. on both ears confirm this.

The Phase. The phase curves do not show the same characteristic distribution as the Abs. curves. For the two lowest frequencies they lie exactly as the curves for normal ears. For the two higher frequencies they lie a little lower.

The mean value ($\bar{X}$) (at 768 Hz.) is 47° (Table 14, page 223). The corresponding mean value for the normal ears at the same frequency is 62° $t = 3.8$. i. e. there is a definite difference. At 1145 Hz. the mean values respectively are 62° and 72°. $t = 2.2$, i. e. the difference is not certain.

These are the same conditions as found in ears with conduction affections due to inflammations or sequels of such (Fig. 18). The dispersion is greater there, but there is no difference between the mean values for conduction affections without or with changes in the drum. The mean value is for 22 ears with the last mentioned affections (at 768 Hz.) $\bar{X} = 48°$. (2 ears, Nos 14 right and 51 right), which have been mentioned before are not included).

The phase corresponding to the 3 mentioned ears with relatively high Abs. do not present conditions differing from the other ears. The phase curve for No. 29 left lies fairly high, but runs exactly as the curve for the right ear of the same patient, and the Abs. on this ear was very small. The curves for No. 52 right and left ear also run about equal but lie rather low.

Two phase curves lie lower than the others for all frequencies. They correspond to right and left ear of No. 104. Just this patient has — perhaps accidentally — slight changes of the drums, both drums being a little dull and somewhat retracted.

The magnitude of the change of Imp. and, hence, the reduction of the amount of energy absorbed may be estimated by

drawing a parallel with the numbers of the normal material.

As was previously mentioned (p. 43), it is necessary to be very careful in drawing conclusions from the recorded absolute values of the small absorptions. At 768 Hz. the mean value of Abs. for all the conduction affections associated with normal ear drums (15 per cent) is not very far from the value for the lowest Abs. curve (about 25 per cent), and at 1145 Hz. the mean value (34 per cent) is greater than the value of the lowest Abs. (about 20 per cent) measured at the graduation of the measuring bridge.

For these two frequencies u has therefore been calculated for each individual ear of the ears of the normal material and for the ears with conduction affections associated with normal ear drums, and from the ratio between the mean values the difference in energy absorption was found.

For the normal material the mean value of $u \cdot 100$ is
at 768 Hz.: 27.9 at 1145 Hz.: 44.2.

For conduction affections
at 768 Hz.: 5.2 at 1145 Hz.: 15.4.

The difference in the amount of energy absorbed at 768 and 1145 Hz. is about 7 and about 5 db respectively.

The loss of hearing is of quite a different range of magnitude, namely, 50—60 db. If it is exclusively caused by the conduction affection, a very considerable reduction of the amount of energy must have taken place, which reaches the labyrinth, whereas the amount of energy absorbed by the tympanic membrane proportionally has changed very little.

In order to get an idea of how great a change of Imp. can be obtained by an isolated stapes fixation, this was examined on fresh, normal temporal bones. Access to the vestibule of the labyrinth was obtained through the internal acoustic meatus by fraising the bottom off and enlarging the canal until a good view both of the basis stapedis and of the fenestra rotunda was obtained. The latter was closed with cement, and the fixation of stapes was achieved either by pressing the point of a probe against the anterior part of basis stapedis or with

cement. Even a very light touch with the probe on the basis stapedis gives rise to a clear change of an adjusted equilibrium on the acoustic bridge. In measuring, however, it is found that the decrease of the amount of energy absorbed by the drum is only about 1—2 db.

A complete fixation of stapes and fenestra rotunda — made on preparations — thus produces only a slight change of the Imp. of the drum. By fixation of the malleus through an opening in tegmen tympani, which is closed afterwards, a very considerable decrease of the Abs. is immediately obtained. In some cases an adjustment of the acoustic bridge to an absolute sound minimum was no longer possible as a sign that the Abs. was 0 or about 0. These experiments have been repeated many times on different temporal bones.

The change of Imp. found on examining living ears with a presumed stapes fixation is thus averagely greater, and in several cases considerably greater, than is found on preparations of normal ears.

How great an effect a stapes fixation will have on the malleus and thus on the response of the drum is dependent on to how great an extent the movement between the several ossicles is possible under these circumstances. An examination of the change of Imp. in the meatus in case of stapes fixation has not been made earlier, on the other hand several examinations have been made about the mobility of the manubrium with and without stapes fixation on normal temporal bones and in cases of presumed stapes fixation on otosclerotic ears.

Dahman by his preparation tests finds that a fairly considerable mobility between the different ossicles must be possible. This holds for influences with fairly great changes of the static air pressure in the meatus, but also in case of sound vibrations *Dahman* is of the opinion that part of the sound energy is lost on account of movements between the ossicles. Also other examiners have found that a stapes fixation alone is not able to cause a distinct *immediate* decrease of the mobility of the manubrium.

It is therefore surprising that *Gunnar Holmgren* in his otosclerosis material in examining the mobility of the hammer

handle under influence of changes of the static air pressure in the meatus with the method mentioned on p. 56 finds that the manubrium often shows curtailed mobility or is completely immobile. Very seldom is the mobility found normal. A finding which — according to Holmgren — does not agree with the classical picture of otosclerosis.

The fixation of the hammer — which *Frenckner* (1939) also finds — can be explained by the results of *Covell*'s histological examinations of the middle ear in otosclerosis. *Covell* simultaneously with the fixation of the stapedio-vestibular joint finds a dislocation of the joints between incus and stapes and between incus and malleus, by which the mobility of the ossicles is decreased. Even when there is no ankylosis between stapes and fenestra ovalis, the movements of the sound conduction chain may be reduced owing to a displacement of the stapedio-vestibular joint into the niche of fenestra ovalis with similar dislocations of the other joints as in total ankylosis. The ligaments show abnormal tensions and relaxations on account of the changed position of the ossicles. The fibers of the tensor tympani are often atrophic. Furthermore *Covell* in many cases finds changes of the ossicles around the joint between incus and malleus, in one single case typical otosclerotic foci in hammer and anvil. These changes also fix the ossicles mutually. The fixation of the stapedio-vestibular joints thus causes a series of changes in the middle ear. They gradually become manifest and are probably dependent on to how great an extent the otosclerotic foci inhibit the movements of basis stapedis.

The results of these examinations of the mobility of the hammer handle in case of stapes fixation on normal temporal bones and on ears with otosclerosis are in accordance with the difference found by Imp. measuring in the meatus in the same two categories of cases. The conditions are here certainly somewhat different. In the first place there is a question of sound vibrations, and in the second place, the Imp. is affected by those parts of the drum which do not follow the hammer handle as a stiff plate.

At sound vibrations with amplitudes of quite a different

range of magnitude than that of the employed static air pressure changes, the sound conduction chain according to *v. Békésy* (1936) vibrates as a homogeneous mass under normal conditions. If the stapes becomes fixed the sound conduction chain is fixed, and a further fixation between the ossicles reciprocally or to the surroundings should be without effect.

The low Abs. in the otosclerosis may be explained by fixation of the sound conduction chain + the cone-shaped part of the drum eventually in connection with increased tension conditions also in other parts of the drum on account of a dislocation of the ossicles.

The greater Abs. in stapes fixation on normal temporal bones may perhaps be due to the fact that there is a greater possibility of loss of energy at movements between the ossicles, because the function of the intra-tympanic muscles is absent (cf. *v. Békésy*'s theory (1936)) about the function of the intra-aural muscles p. 113). There may possibly also be a difference in the conditions of the tension in the drum of normal ears and of ears with otosclerosis.

X. THE IMPEDANCE IN PERCEPTION AFFECTIONS

A. UNILATERAL PERCEPTION AFFECTIONS

Remarks on the function tests.

This refers to 10 patients with unilateral hard hearing and normal ear drums. In 3 *cases* one ear is totally deaf, in 6 *cases* the air conduction curve drops towards the high frequencies. In one of these patients, No. 50, the diagnosis perception affection is made alone on this and on the anamnesis. In 5 cases (Nos. 77—105—110—115—119) Fowler's test also is suggestive of perception affection. One patient (No. 115) has certainly suffered from acute otitis during childhood, but the severe loss of hearing began many years later, even if there was a slight loss of hearing on the affected ear since childhood. The conditions mentioned in the conclusion justify the as-

sumption of a perception affection however. *In* 1 *case* (No. 102) the air conduction curve runs horizontally and the loss of hearing is sooner a little more pronounced for the deep and medium frequencies. Also this patient has had an acute otitis during childhood, but the reduction of hearing was not discovered till about 30 years later. Owing to the unequivocal result of Fowler's test the patient has been included among the perception affections.

No diagnosis has been mentioned in the reports but it can only be neurolabyrinthopathia acustica, surditas or the like.

The Impedance in the unilateral perception affections.

The Absorption. In Fig. 23 the Abs. curves are plotted for the 10 ears with loss of hearing as well as for the 10 normal ears. Almost all the curves lie within the average range of dispersion for normal ears. (cf. Fig. 16. Unilateral conduction affections with changes of the drum, besides the 2 ears with unilateral conduction affection and normal drums).

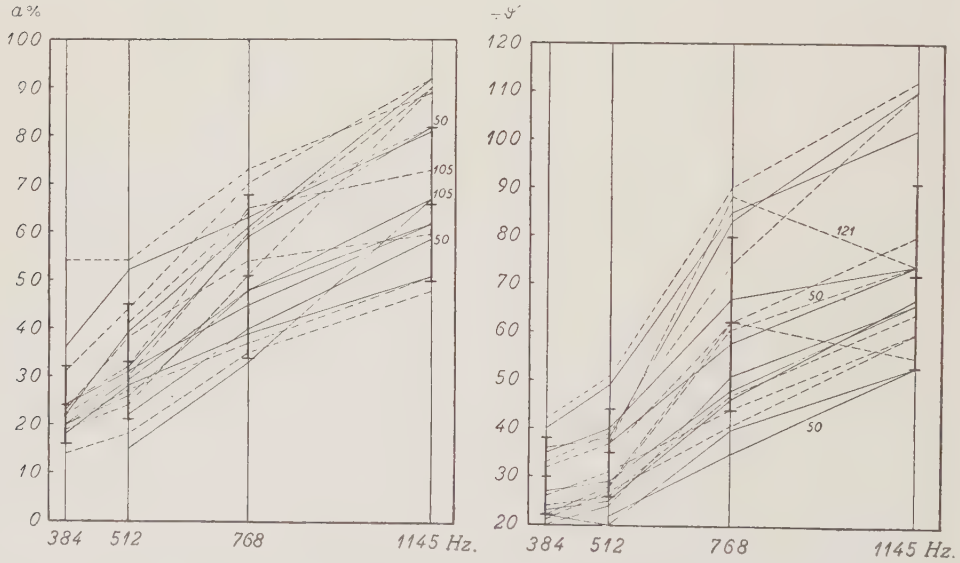


Fig. 23. Unilateral perception affections. (Absorption and Phase curves).
———— normal ears. -------- pathological ears.

Mean value and standard deviation are shown in the table below:

	Normal ears		Hard-hearing ears		
Freq.	$\bar{X}_a$	s_a	$\bar{X}_a$	s_a	n
384	23.0	7.1	25.9	13.5	7
512	31.0	10.6	34.0	10.5	10
768	48.0	11.2	55.8	12.9	9
1145	71.7	13.3	73.6	18.2	8

The difference between the sound and the pathological ear of the same patient is, as the mean values show, small, but runs for all the frequencies in the same direction, namely, a somewhat greater Abs. on the path. ear.

Only in 2 cases (Nos. 50 and 105) is there a greater difference. For 512 Hz. the difference between the Abs. on the normal and the hard-hearing ear is resp. — 19 % and — 17 %, for 768 Hz.: — 24 % and — 32 %. An explanation of the greater difference in these two cases cannot be given. That the Abs. is greatest on the hard-hearing ear is perhaps, casual, but it accords with the result of Lucae's examinations of the few cases of diseases of the inner ear which he examined.

The 3 totally deaf ears do not show any deviation from the ears with reduced hearing. The difference between the Abs. of the normal and deaf ear is $\leqq 10$ %, in two cases negative, in one positive.

The Phase. As shown in Fig. 23 the phase curves also lie in the dispersion area of the normal curves. The mean values for the normal and opposite hard-hearing ears are:

Freq.	Normal ears ($-\bar{X}_\vartheta$)	Hard-hearing ears ($-\bar{X}_\vartheta$)
384	29.0°	28.6°
512	32.6	35.4
768	57.0	63.2
1145	76.5	76.9

The difference between the normal ear and the hard hearing ear is — as well as for the Abs. — small, in several cases only a few degrees. Only in 1 case there is a greater difference for 768 and 1145 Hz., where the phase is greatest for the hard hearing ear. The difference in the Abs. was, as mentioned,

also fairly great. The localisation of the Imp. is, however the most normal for the hard hearing right ear, whilst that of the normal left ear deviates from it, uncertain for what reason. The mean figures for 512 and 768 Hz. also show a little difference in the direction of a greater phase on the hard hearing ear. The completely deaf ears do not show deviating conditions. One of them (121 left) certainly has a numerically very great phase for 768 Hz., but to the three other curves which lie high (especially for 1145 Hz.) corresponds partly 1 normal ear (102 left), partly two ordinary deaf ears (102 right and 77 right). These 4 ears also have a high Abs. especially for 1145 Hz.

The Impedance. Neither the Abs. nor the phase shows any definite difference between the healthy and the hard-hearing ear. The Imp. is thus probably the same. The slight difference which the mentioned figures possibly express, run in the opposite direction of what was seen for the unilateral conduction affections on account of inflammations (or consequences of such) where the difference went in the direction of minor Abs. and *minor* phase for the hard-hearing ears.

B. BILATERAL PERCEPTION AFFECTIONS

Remarks on the function tests.

There were examined 9 patients with bilateral perception affections.

Eight are classified after the proportion bone conduction/air conduction which is $\geq 2/3$. In 7 of these cases the other function tests also speak for perception affection (Nos. 54—65—67—70—71—106—107). One patient No. 63 has a relatively good hearing for the high frequencies per air as well as per bone conduction. In addition to the very considerable hearing loss for the low and middle frequencies per air conduction as well as especially per bone conduction, however, the anamnesis also is suggestive of perception affection.

One patient No. 36 cannot be classified after the proportion

bone conduction/air conduction, as the bone conduction is very good for 256 and 512 Hz., very bad from 1024 and upward. All the other tests and the anamnesis, however, are suggestive of perception affection as recorded in the case reports.

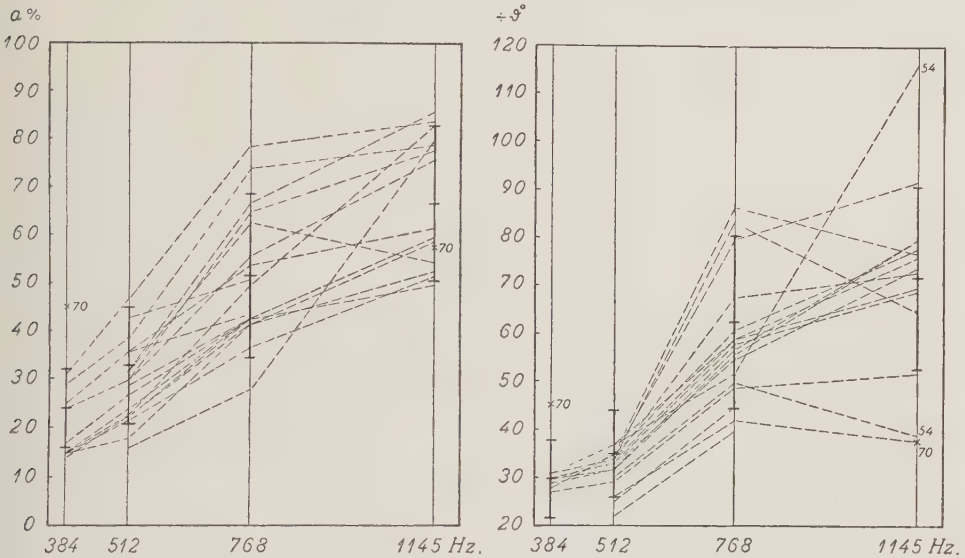


Fig. 24. Bilateral perception affections. (Absorption and Phase curves).

One patient No. 70 was totally deaf on the one ear. This also holds for the first examination of No. 71, but the hearing had improved at the two subsequent examinations.

The Impedance in Bilateral Perception Affections.

The Absorption. In Fig. 24 the Abs. curves for all 18 ears are plotted, for No. 71 only the result of the first examination is included. The curves just as for the unilateral perception affections are seen to lie within the spreading area of the normal ears. The curve lying lowest at 512 and 768 Hz. corresponds to the right ear of No. 54.

One of the deaf ears does not present anything special (No. 71). The other (No. 70 left ear) has a fairly high Abs. for 384 and 1145 Hz., for 512 and 768 Hz. an adjustment was not

possible (no minimum), probably because the Abs. is so high that it exceeds the measuring capacity of the apparatus. The opposite ear with a moderate loss of hearing had a relatively low Abs. On the 7 patients the hearing on both ears is practically equal. Calculating the difference between the mean value of the Abs. on the best and the worst hearing ear, we have + 3% for 512 Hz., — 0.4% for 768 Hz., i. e. there is no difference.

The left ear of the patient No. 71 was, as already mentioned, examined three times. The first time 5 days after the onset of an acute complete deafness, the second time three weeks later, and the third time 1 month after the second examination. The hearing has improved much between the 1st and 2nd examinations, slightly between the 2nd and third. The Abs. at all 3 examinations was quite the same for all 4 frequencies. The three examinations show how exact the measuring may be reproduced, when no other circumstances interfere.

The mean values of the Abs. and the phase as well as the number of ears examined at the different frequencies are shown in the Table under the Phase.

The Phase. The phase curves lie — as for the unilateral perception affections — in the dispersion area of the normal ears (Fig. 24). The mean values of the phase as well as of the Abs. and the number of examined ears are shown in the following Table:

Freq.	Abs. ($\bar{X}_a$)	Phase ($-\bar{X}_\vartheta$)	Number
384	22.3%	30.9°	11
512	29.8%	31.9°	17
768	51.8%	58.9°	17
1145	68.2%	69.8°	16

The difference between the normal figures and these figures is at most 3% and 3° i. e. there is no difference.

No. 70 left ear which was deaf, and which has been mentioned under Abs., shows for the two frequencies, where an adjustment was possible, deviating conditions also for the phase. At 384 Hz., it is very high, for 1145 small. The phase for 54 right and left ear deviates for 1145 also from the other ears

examined, without any demonstrable cause of the divergence. As is evident from the data mentioned, Imp. shows the same conditions as in the normal ears. The small difference found, in the unilateral perception affections, between the hard-hearing and the normal ear, is even smaller between the bilateral perception affections and the normal material and does not point in any definite direction.

XI. MÉNIÈRE'S SYNDROME

In this group 4 patients with unilateral and 6 patients with bilateral loss of hearing were examined. All the cases are patients suffering from periodical attacks of vertigo, reduction of hearing, unilateral or usually most pronounced on the one ear, and buzzing, which in some cases exacerbated during the attacks.

In 8 cases attacks of nystagmus were observed. In two cases of unilateral hearing loss it was directed towards the normal, and in 2 cases towards the affected ear. In one of the cases, where it was directed towards the normal ear, a change of the nystagmus was observed after half an hour. In 2 cases of bilateral loss of hearing it was directed towards the most affected ear, in two cases towards the best ear (for two patients information as to nystagmus was not available).

In none of the cases did the general examination (incl. neurological and opthalmological examinations) afford any definite criterion for a diagnosis other than Morbus Ménière. From the results of *the acoustic function tests* the following may be stated.

The Patients with Unilateral Hard-Hearing.

There is in all the four cases (Nos. 28—37—68—80) a considerable loss of hearing on the affected ear. The air conduction curve of the audiogram runs an almost equal course, mainly horizontally. Li is elevated. The upper limit (Ls (a)) for the first two patients is essentially equal on the right and left ear

and about normal. For No. 68, it is 3000 Hz. lower on the hard hearing than on the normal ear where it is slightly better than corresponding to the patient's age. For No. 80 there is a downward displacement at 4000 Hz., Ls, for the normal ear corresponds to the patient's age. Weber's test has not been performed, but bone conduction for a^1 on the mastoid process is, for the three patients where it was tested, best on the normal side (the 4th patient was only tested on the sound side).

Fowler's test shows a pronounced regression in all the 4 patients. The bad hearing for the low frequencies and, in comparison with what is seen in perception affections the relatively good hearing for the high frequencies, may be utilized as a basis for the diagnosis: conduction affection. The equal reduction of hearing for the whole range of frequencies may with equal right be interpreted as indicating perception affection.

The most correct thing will therefore be to say that, after the result of the audiometer examination and the tuning-fork and monochord tests, it is impossible to decide whether there is a question of one localization or another.

Fowler's test gives a plain result however.

The Patients with Bilateral Hard-Hearing.

For the 2 patients (Nos. 32 and 53) the course of the air conduction curves is about equal. There is a difference between right and left ear of 15—40 db. Fowler's test indicates a perception affection for No. 32, for No. 53 it points decidedly to it, as there is an "over-recruitment" for all frequencies. The other tests permit of no definite conclusion. (The hearing of No. 32 is best at 2048, and decreases afterwards for the two highest frequencies. For No. 53 the curve runs horizontally up to this frequency and then falls slightly. Li shows a considerable elevation for the most hard hearing ear of No. 53, a slightly elevation for No. 32. Ls is displaced slightly downward per air conduction as well as per bone conduction for No. 32. No. 53 presents a considerable downward displacement of Ls (a) on the most hard-hearing ear). The audition of 3 patients (Nos. 79—94— and 98) is very bad per bone con-

duction. In Nos. 79 and 98 the normal Ls (m) goes against a perception affection. This applies to No. 98 too with regard to the shape of the air conduction curve which rises at the two highest frequencies. In patient 94 all the tests indicate a perception affection. For 1 patient No. 74 there is only the audio-

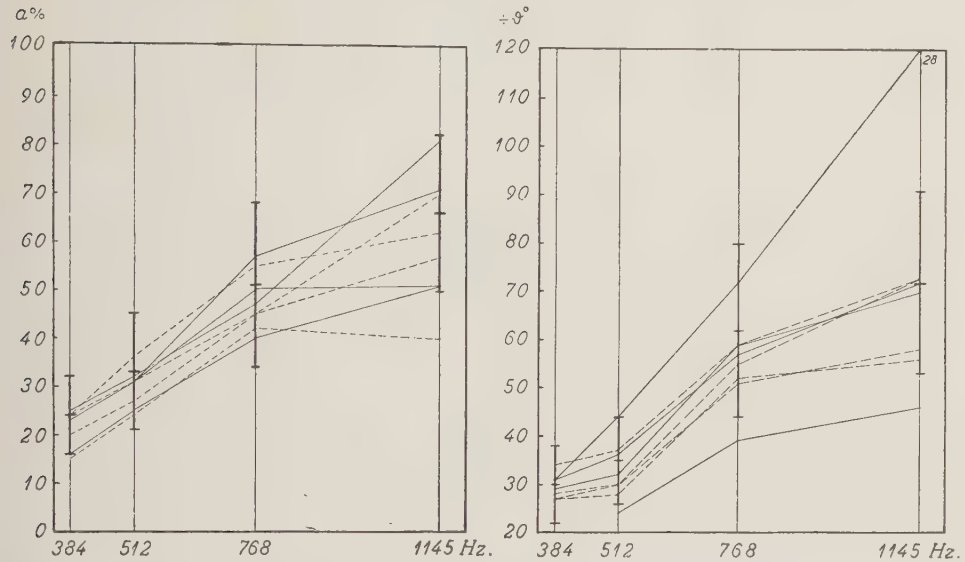


Fig. 25. Ménière's syndrome with unilateral hearing loss.
———— normal ear. -------- hard-hearing ear.

gram. The proportion between bone conduction and air conduction indicates a perception affection. Only at 1024 Hz. is the proportion $<2/3$, for all the other frequencies the hearing is reduced about equally per bone conduction and air conduction.

The two tests on which particular stress was laid, the proportion bone conduction/air conduction and Fowler's test, decidedly indicate a perception affection in all 10 cases.

The Impedance in Ménière's Syndrome.

The Absorption and the Phase.

In the 4 cases with *unilateral hardness of hearing* all values for the Abs. as well as for the Phase are entirely within the dispersion area of normal ears (Fig. 25).

The difference of the Abs. between the healthy ear and the hard-hearing ear is very small, for the 3 lowest frequencies $\leqq 5\,\%$, excepting No. 80 at 768 Hz., where the difference is $+ 12\,\%$. For 1145 Hz. it is 11—14 %. In 3 cases the difference for all frequencies is positive, i. e. the Abs. is slightly greater

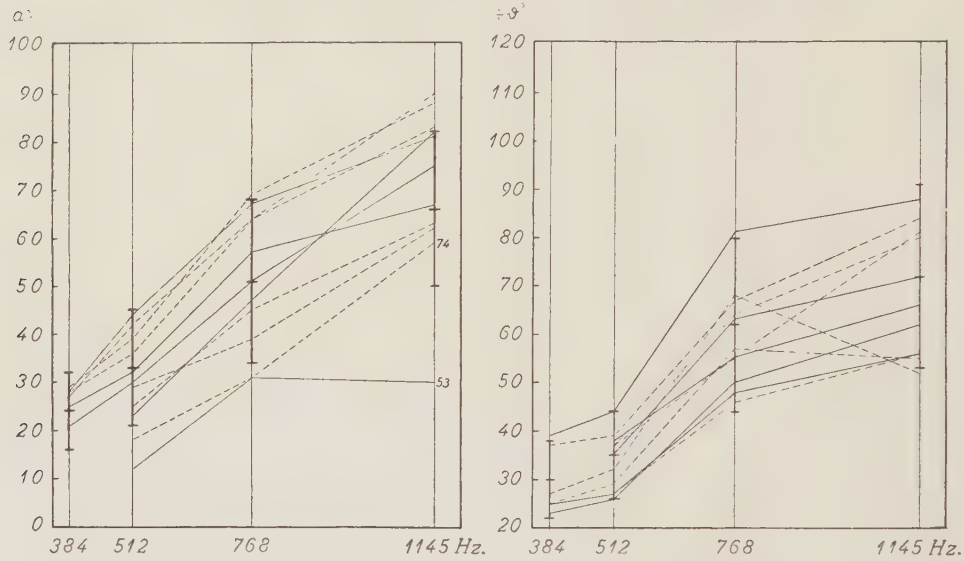


Fig. 26. Ménière's Syndrome with bilateral hearing loss.
———— best hearing ear. -------- worst hearing ear.

for the nomal ear, it is negative in 1 case, also for all the tested frequencies.

The difference in the Phase is likewise small, with the exception at 1145 Hz. in case No. 28 where it is 47 °, due to the fact that the phase for the best hearing ear is exceptionally great (120 °).

In the 6 cases with *bilateral hearing loss* Fig. 26 the Abs. curves for the 11 examined ears — with the exception of 2 — lie within or above the mean dispersion area of the normal values. 2 curves lie slightly lower (Nos. 74 right and 53 left). Neither of these two patients, however, had completely normal drums, but the opposite ears — where the Abs. was fairly great — had the same slight changes. In one of the cases the Abs. was at the lowest on the deafest ear, No. 74 right, in the

other, on the ear with the best audition 53 left, the lowest lying curve.

In one of the cases (No. 32) the Imp. measuring was only made on one ear. There is a considerable reduction of hearing on this ear, and the vertigo has with great probability been elicited from it. The hearing on the opposite ear is about normal. The Abs. on the hard hearing ear is relatively high (29 and 39 % for 512 and 768 Hz.).

The difference of Abs. on the best and worst hearing ear is negative in 3 of the 5 cases, i. e. the Abs. is greatest on the worst hearing ear. It is positive in 2 cases (Nos. 74 and 98). In the last mentioned case the difference is quite small. In No. 74 which has been mentioned above, the difference is a little greater and has probably some connection with the described slight changes of the drums (which in No. 53 gives a somewhat greater difference in the opposite direction).

The Phase curves lie corresponding to the range of dispersion for the normal curves. The difference between the two ears is $\leqq 5°$ for the 2 lowest frequencies. For the two highest frequencies it is in some cases a little greater. The difference does not run in any special direction, as the difference between the best and worst hearing ear in just as many cases is positive as negative.

The Imp. of 10 patients selected at random, with normal ear drums and Ménière's syndrome, thus does not present any deviation from the Imp. of normal ears (and the Imp. in perception affections). The same holds for the contraction of the intra-aural muscles, which is discussed later.

The reason why these patients were examined is that it was thought to be possible to demonstrate a change of Imp. if the hearing loss — according to Mygind-Dederding's theory — in all or some of the cases was due to a reduction of sound conduction caused by an increase of pressure in the labyrinth.

Before the complete fixation of stapes in the preparation experiments, discussed under conduction affections associated with normal ear drums, the effect was examined, which an increase of pressure in the labyrinth produced on the Imp. measured in the auditory canal. This was done by fraising

an opening to the vestibule of the labyrinth through the bottom of the internal acoustic meatus. A pipe was inserted tight-fitting into the opening, and the pressure was changed by placing a water reservoir — connected with the pipe by a rubber tube — at different heights above or beneath the preparation.

A change of the labyrinth pressure of no more than 10—20 cm. of water gives rise to a distinct change of an adjusted balance on the measuring bridge: on measuring, however, the change, which chiefly is a decrease of Abs., is found to be but slight (a few per cent). A change of pressure of 100 cm. of water was found to produce a reduction of Abs. of up to 20 per cent.

To draw conclusions from these experiments, however, and apply them to the change of Imp. on the living ear in case of an unknown rise of pressure in the labyrinth is only possible to a very little extent. It seems warrantable, however, to anticipate that even a slight increase of pressure in the labyrinth will cause a measurable change of Imp. in the auditory canal.

Both on parallelling the Imp. measured on different ears (as on comparing the bilaterally hard-hearing Ménière patients with the normal material of patients) as well as on comparison between right and left ear of the same patient (as is feasible in cases of unilateral hard hearing), a considerable dispersion of the measurings in proportion to the difference intended to be demonstrated must be reckoned with.

The negative result can at the highest be interpreted as *indicating* that a reduction of the transport of energy to the labyrinth has not taken place. Only examination of a very comprehensive material can afford a result to which may be attached importance.

An easier and greater possibility of demonstrating a slight difference of Imp. is, as was previously mentioned, afforded by repeated examination of the same ear. A negative result of Imp. measuring on the same ear both during, after and, best, also prior to a Ménière attack associated with loss of hearing or increased hearing loss will be of greater importance. On the other hand, there will also in this way be a greater chance

of demonstrating a change of Imp. in the living ear, if the hearing loss actually is due to a change of the energy transport to the labyrinth on account of an endolabyrinthine rise of pressure. Such examinations have not been performed, but they are to be expected with interest.

XII. DOUBTFUL DIAGNOSES

In this group 3 cases with unilateral hardness of hearing have been placed. Fowler's test gives an uncertain result, and neither the anamnesis nor the other tests afford a clue to the diagnosis. Further 1 patient with bilateral hard hearing at the high frequencies, who certainly is of the perception type, but where the hearing is about normal for the frequencies used at the Imp. measuring.

The first of the unilateral cases (No. 73) presents a very low Abs. on the hard-hearing ear, but also a low, although a little greater Abs. on the normal ear. The muscle reflex cannot be elicited on either ear.

This patient resembles No. 66 who likewise presented a somewhat low Abs. on the normal ear.

The next two patients (Nos. 112 and 113) have a high Abs. on the hard-hearing ears and the Abs. practically is the same on the hard-hearing and the normal contralateral ear. A strong muscle reflex can be elicited on the hard-hearing ears. The Phase is smaller on the hard-hearing ear of No. 73; in the two other cases rather larger on the hard-hearing ear than on the normal ear.

Judging from the Imp. measuring there should thus be no doubt that the firstmentioned patient has a conduction affection which probably is responsible for the hard hearing, and that the two other patients do not suffer from a conduction affection. The diagnosis per exclusionem must therefore be perception affection.

The last patient (No. 100) undoubtedly has a slight bilateral perception affection, as suggested both by the anamnesis and the functional tests. The Abs. measuring as well as the muscle reflex show normal relations.

XIII. THE ACOUSTIC REFLEX CONTRACTION OF THE INTRA-AURAL MUSCLES ON HARD-HEARING EARS WITH NORMAL EAR DRUMS

Conduction affections with normal drums.

The muscle reflex cannot be elicited on either of the ears of the patients with bilateral hearing loss. Of the 2 unilateral hard-hearing patients No. 21 was not examined. On No. 66 an unmistakable reflex can be elicited on the normally hearing left ear from the right very hard-hearing ear, but not inversely.

That means to say that a reflex cannot be elicited on 25 of the 26 ears tested. One ear was not tested.

Perception affections.

The conditions are here a little more complicated as muscle reflex can be elicited in many cases, in others not, without quite definite dependence on the degree of the loss of hearing. *From* none of the 3 completely deaf ears could a reflex be elicited however.

The connection between the hearing loss and the muscle reflex is the most evident in the unilateral perception affections. The condition is here as follows M.R. + means that the muscle reflex can be elicited on the ear concerned from the opposite ear, M.R. — that it cannot be elicited from the opposite ear.

	MR +	MR —	Number of ears
Normal ears	2	8	10
Hard-hearing ears	9	1	10

A muscle reflex from the opposite normal ear can be elicited on all the hard-hearing or deaf ears — with the exception of 1. This one exception is No. 102 where a muscle reflex can be elicited on the normal ear, but not on the hard-hearing one. This result is so remarkable that the possibility of there being an error (slips of the pen) must be taken into consideration.

Only in 2 cases can a reflex be elicited on the normal ears. The first is discussed (No. 102). On the other (No. 119) the

reflex could be elicited in spite of a very considerable loss of hearing on the opposite ear.

Three of these ears were, as already mentioned, completely deaf (Nos. 83, 120 and 121). A very distinct muscle reflex could be elicited on all of these, but not on the opposite normal ear from the deaf ear. This shows — in accordance with the result of the examinations of the other unilateral perception affections — that in these cases anyhow it has been impossible to elicit the M.R. by conduction of the sound from one ear to the other either through air or bone conduction.

In four out of 8 *bilateral hard-hearing* patients a muscle reflex can be caused on both ears, in 2 of them reflex can not be elicited on any of the ears. 1 patient (No. 70) has not been tested. On 1 patient with unilateral total deafness a muscle contraction could be elicited on the deaf ear, but not on the contralateral hard-hearing ear, exactly as described above. In this case (No. 71) the hearing on the deaf ear was restored whereafter the reflex could be elicited on both ears.

In 1 case, where the muscle contraction *could be* elicited on both ears, there was a very considerable loss of hearing (No. 67), in 1 case where reflex *could not* be elicited there was only a moderate loss of hearing at the deep and medium frequencies, but a pronounced loss of hearing at the high frequencies (No. 36). The extent of the hearing loss thus is not in all cases decisive of whether the muscle reflex can be elicited or not.

Ménière's Syndrome.

On 4 unilaterally deaf patients of this category a muscle contraction could be elicited on both ears in spite of a very considerable hearing loss on the hard-hearing ear in all cases. From 2 of the hard-hearing ears (Nos. 37 and 80) however, only a very slight change of the adjusted minimum was audible.

Of the 6 *bilaterally deafened patients* with Morbus Ménière 5 were only tested for the muscle reflex. It could be elicited on all the ears except one (No. 53). The Abs. on this ear was fairly small, the hearing loss on the opposite ear was moderate.

Dubious Diagnosis.

The muscle reflex is mentioned under Imp., Chapter XII.

XIV. COMPARISON OF THE CLASSIFICATION OF THE MATERIAL ACCORDING TO THE SUBJECTIVE FUNCTIONAL TESTS AND THE CLASSIFICATION ACCORDING TO THE IMP. MEASURING

The preceding sections give the result of the Imp. measuring performed on each of the groups formed by the classification of the patients according to the subjective function tests. Each group has been compared with the normal material, and the individual ears which differed from the average in each group were discussed.

In this chapter the different groups will be compared mutually and the result of the Imp. measuring will be parallelled with the classification obtained according to the subjective function tests.

The total result of the Imp. measuring on the material of patients with loss of hearing and normal ear drums is shown in Table 14 and in Figs. 27 and 28. In Table 14 are recorded mean value, mean error on the mean figure, standard deviation and the number of ears which have been examined in the 3 main groups: conduction affections, perception affections, and Ménière's Syndrome. For comparison the normal figures are quoted. In Figs. 27 and 28 the values for all the hard-hearing ears with normal drums are recorded in the complex plane for the 2 frequencies: 512 and 768 Hz. which have proved to be best suited for this. In addition the areas are sketched in which are delimited by $\overline{X} \pm 2s$ for the Abs. as well as for the Phase, and finally the average dispersion areas for the normal ears. These dispersion areas only refer to Abs. and Phase. Calculated for the very complex Imp. they will look somewhat different, but be smaller.

It is seen how the values, as shown above, lie in two groups: Perception affections, Ménière's Syndrome (and the normal ears) with the highest Abs., and conduction affections with normal ear drums with lower Abs.

The object of the Imp. measuring is above all to try to contribute to the solution of the differential diagnosis between conduction and perception affection. It is therefore necessary directly to compare the result of the Imp. measuring performed on these two groups, even if it probably is the same as to compare conduction affections with the normal ears, for, judging by the results at hand it looks as if the Imp. in perception affections does not differ from the Imp. of normal ears.

The figures in Table 14 show the result of the 2 directly measured magnitudes Abs. and Phase.

Table 14. Mean value, mean error on the mean figure, standard deviation and the number of ears which have been examined at each frequency in the 3 main groups: conduction affections, perception affections and Ménière's syndrome. For comparison the normal figures are quoted.

	Absorption			Phase			
Freq.	$\bar{X}$%	e%	s%	$-\bar{X}^\circ$	e°	s°	n
Normal ears.							
384	23.7	± 1.3	± 8.2	30.2	± 1.2	± 7.7	41
512	32.7	± 1.6	± 11.8	34.8	± 1.2	± 8.8	57
768	51.1	± 2.3	± 17.1	61.6	± 2.5	± 18.3	55
1145	66.1	± 2.3	± 16.0	72.4	± 2.6	± 18.7	50
Perception affections except Morbus Ménière.							
384	23.0	+ 2.7	± 11.4	29.9	± 4.3	± 18.0	18
512	31.5	± 1.8	± 9.4	33.2	± 1.3	± 7.0	27
768	53.2	± 2.6	± 13.2	60.3	± 3.0	± 15.0	26
1145	70.1	± 3.1	± 15.1	71.6	± 6.3	± 31.0	24
Ménière's syndrome.							
384	24.1	± 1.4	± 4.4	29.2	± 1.7	± 5.5	10
512	29.9	± 2.3	± 8.8	33.1	± 1.4	± 5.4	15
768	49.3	± 3.2	± 12.3	58.1	± 2.4	± 9.2	15
1145	66.1	± 4.2	± 16.4	67.4	± 3.1	± 12.1	15
Conduction affections with normal drums.							
384	5.9	± 1.0	± 4.4	31.3	± 1.8	± 7,5	18
512	7.2	± 1.0	± 5.0	35.5	± 1.4	± 7.4	26
768	14.7	± 1.4	± 7.2	47.2	± 2.2	± 11.5	26
1145	34.4	± 2.8	± 13.9	62.2	± 3.6	± 18.1	25

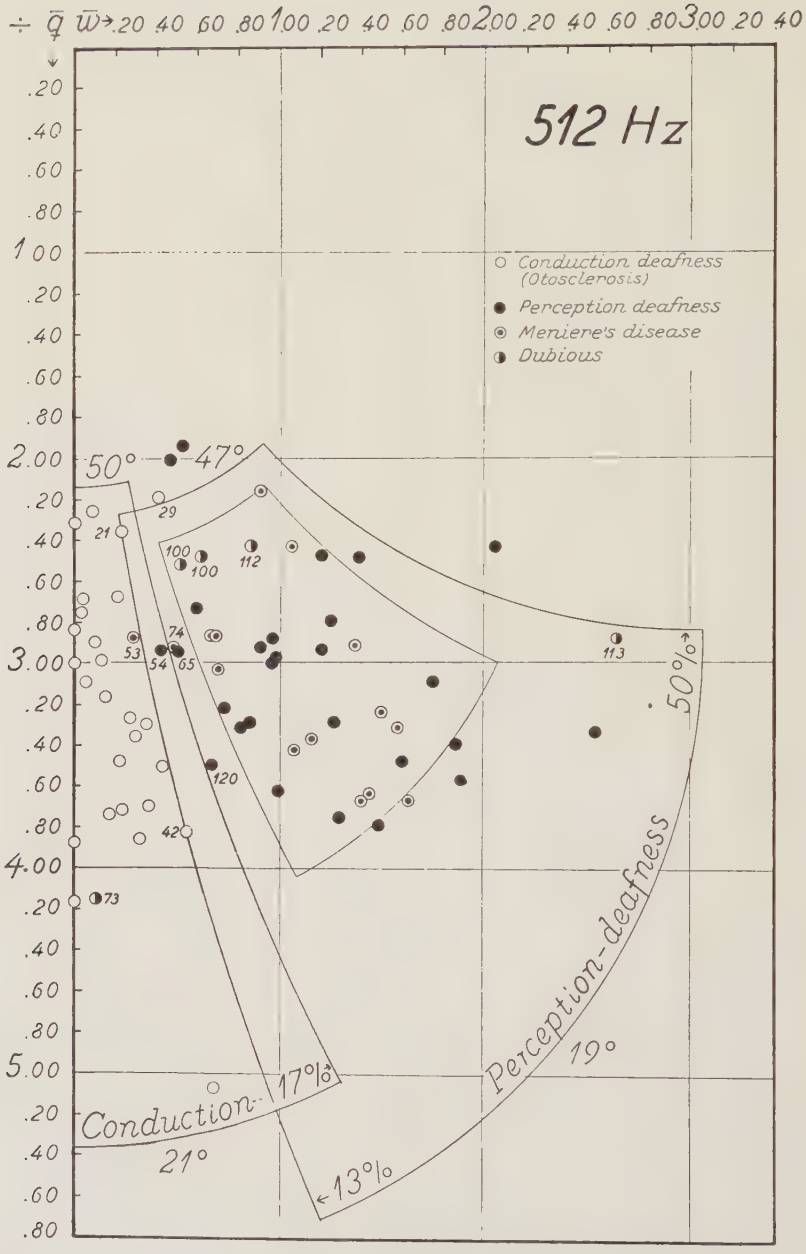

÷ q̄ w̄ → .20 .40 .60 .80 1.00 .20 .40 .60 .80 2.00 .20 .40 .60 .80 3.00 .20 .40
512 Hz
Conduction deafness (Otosclerosis)
Perception deafness
Menière's disease
Dubious
50°
47°
50%
Perception-deafness
19°
17%
Conduction
21°
13%

Fig. 27.

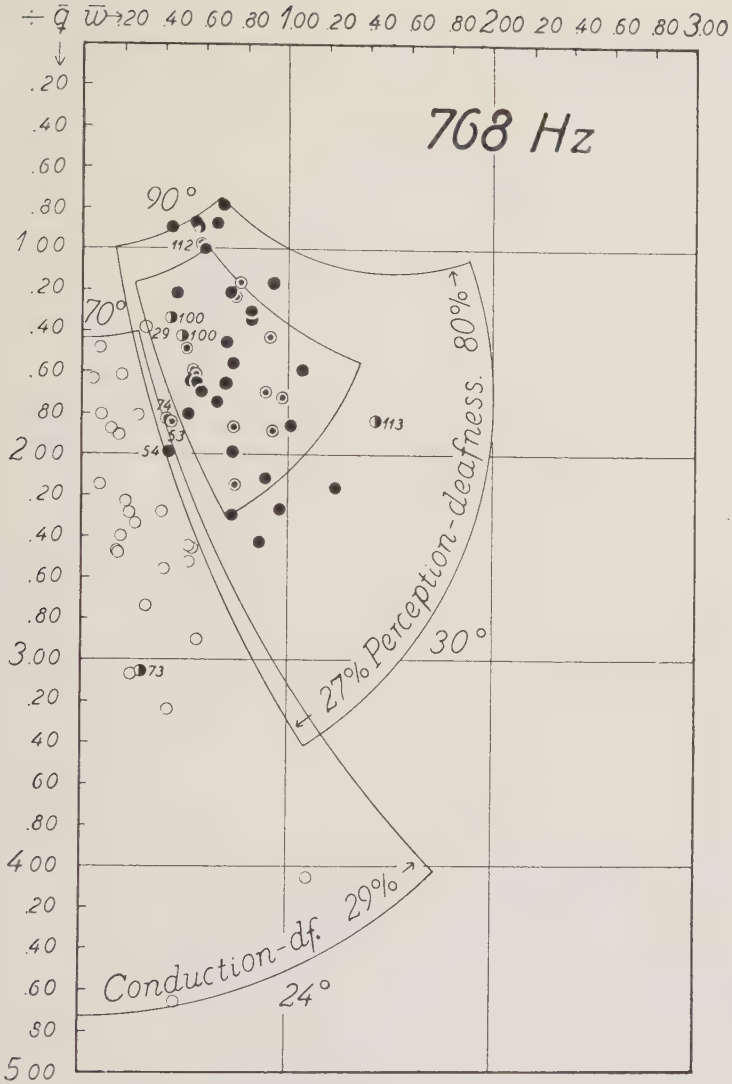


Fig. 28.

Fig. 27 and Fig. 28. All the examined hard-hearing ears with normal drums plotted in the complex plane. The signatures denote the diagnoses according to the subjective function tests. The areas which are delineated by the mean value ± 2 times the dispersion of the Absorption and Phase for the conduction affections as well as the perception affections are noted down. The small field is the mean dispersion area of the normal material.

As regards Abs. the mean dispersion areas which include 2/3 of the values, lie completely separated at all 4 frequencies. Within the average value $\pm 2 \cdot$ the standard deviation about 95 % of the values are situated. With regard to the separation between the two groups naturally only the highest value for the conduction affections and the lowest value for the perception affections is of any interest. These two areas encroach very little upon each other at 512 and 768 Hz., considerably more at 384 and 1145 Hz. The figures are as follows:

	384	512	768	1145
Highest value for conduction affections.	14.4%	17.2%	29.1%	62.2%
Lowest value for perception affections.	0.2%	12.7%	26.6%	39.9%

The difference between the two groups appears most clearly for 512 and especially for 768 Hz., where the common area (the dubious zone) is only 2.5 %. The great overlapping at 384 Hz. is due to the great dispersion of the few ears with perception affections which have been examined at this frequency. Causes of the greater measuring uncertainty at 384 and 1145 Hz. have been mentioned before.

Only at 768 Hz. does the Phase show a smaller difference, as it is somewhat greater in perception affections than in conduction affections. The difference between the mean figures is 13°, which according to a statistical calculation should be real. For 512 and 384 Hz. the mean figures are equal. For 1145 Hz. the Phase is somewhat greater in perception affections than in conduction affections, but the dispersion is very great.

In Figs. 27 and 28 is shown how this classification looks in the complex plane. The signatures denoting the grouping after the subjective functional tests show how the single ears after the Imp. measuring are grouped with the same ears as perception affections and conduction affections, which are diagnosed thus according to the subjective functional tests. The single ears which lie in the border zone or in the "wrong" area are

marked with the number of the patient. They have all been mentioned earlier.

In these figures it is also seen how $\bar{w}$ and $\bar{q}$ have altered and that a classification alone after $\bar{q}$ is not possible and after $\bar{w}$ will not be so good as after Abs. The numerical value of the Imp. itself is not changed or but slightly changed and thus cannot be used for a classification. On the other hand a classification according to the argument of the Imp. or after u. may be thought to be possible.

The curves with constant u follow, as was mentioned (p. 26), in these areas fairly closely the Abs. curves, but a classification according to u would have the advantage of directly showing the correct difference in the energy absorption. The mean value and standard deviation of u for 768 Hz. were calculated for ears with conduction affections and with perception affections, but a better differentiation between the two groups than by classification according to the Abs. was not found.

As the Abs. is the magnitude which is directly measured and which — as a rule — also gives a good impression of the changes in the energy absorption, we have chiefly used it and have also in the diagrams in the case reports plotted the Abs. curves (instead of the u curves).

However, for the purpose of finding the adequate expression of a difference or change in the energy absorption u was always used.

A direct comparison also between the single links of the subjective functional tests and the Imp. measuring would be of considerable interest, but the material is too small, nor were the single tests carried out systematically enough.

Of the two tests to which the greatest attention has been paid, there is, good concordance between the results of Fowler's test and the Imp. measuring.

Fig. 29 and 30 give a survey of the classification of the bilateral hard-hearing patients according to the relation bone conduction and air conduction and after the Abs. The ratio bone conduction/air conduction has been shown logarithmically on the axis of abscissas and the Abs. on the ordinate.

As an expression of the ratio bone conduction/air conduction is thus used tg to the angle which is formed by a line from the zero point of coordinates to the point, corresponding to the ear, and the axis of abscissas in the diagram proposed by *Foght* (Fig. 20). It would of course have been more correct as *Foght* proposes, to use the angle formed by a line from the middle of the normal group to the point which corresponds to the ear, and the axis of abscissas. If the audiometer is graduated correctly the two methods are equal, as the mean value for the normal ears lies in the zero point of coordinates. This is not quite the case with the used audiometer. As is seen in Fig. 20 the normal values lie slightly below 0 for bone conduction as well as for air conduction (the mean value at 512 Hz. of the best bone conduction is: — 2.8 db and the best air conduction of both ears: — 1.8. db.) The

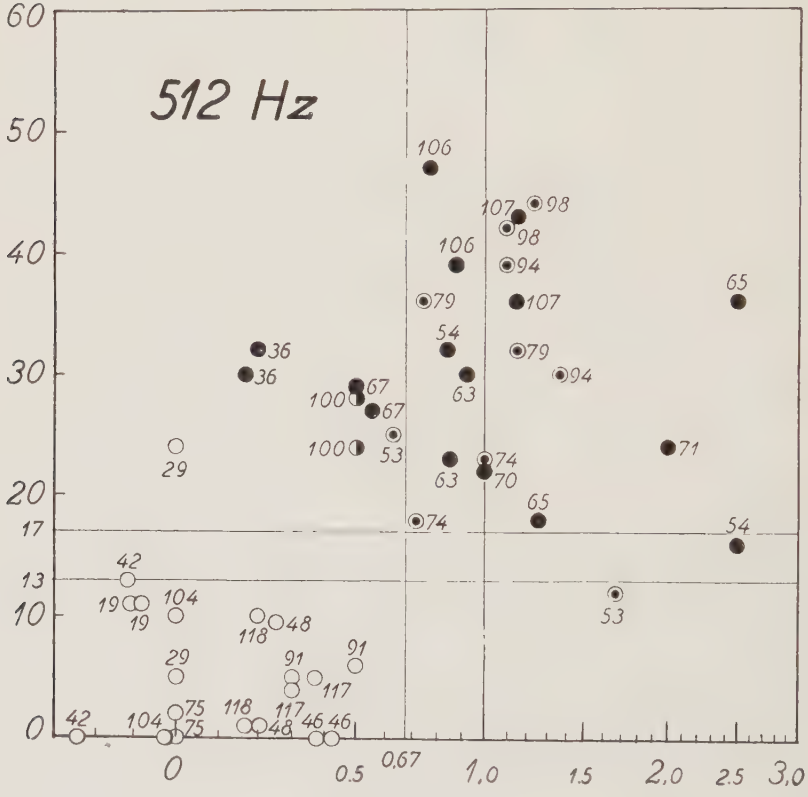


Fig. 29.

Fig. 29 and 30. Classification of the ears of bilaterally hard-hearing patients with normal drums according to the ratio between bone conduction and air conduction (abscissae) and after the absorption (ordinates). Explanation of the signatures see Fig. 27.

relation bone conduction + 2.8/air conduction + 1.8, which is the tg to the angle proposed by *Foght* ought to have been used or the audiograms ought to have been corrected. *Foght* has not done this nor has it been done here because the error is so small. There will be a slight deviation of the values towards the right, but that is of no importance for the grouping of the material.

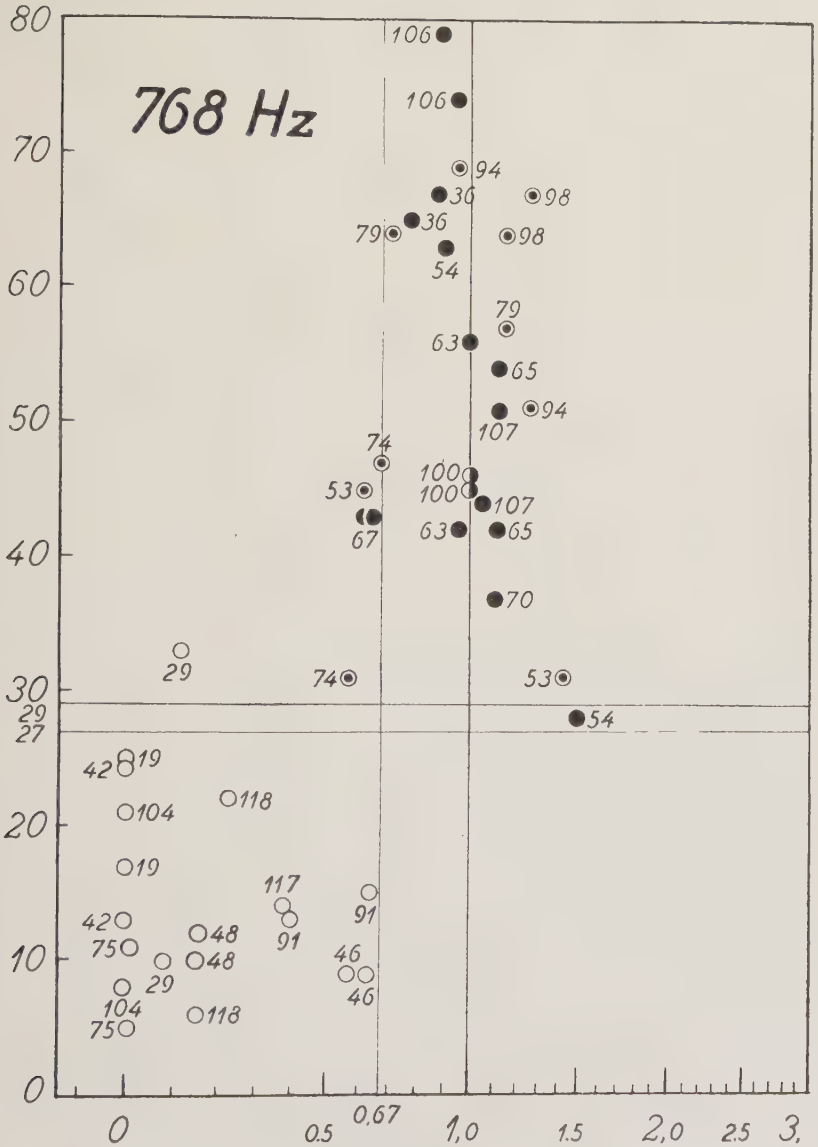


Fig. 30.

For 512 Hz. both the audiometer test and Imp. measuring were carried out. For 768 Hz., on the other hand, no audiometer test was made. No isolated hearing loss being found in this range of frequency, the mean value of the loss of hearing for 512 and 1024 Hz. was used which is assumed with good approximation to express the hearing loss for 768 Hz.

On the axis of abscissas 1 indicates the equally reduced hearing per bone- and air conduction, 0 the normal hearing per bone conduction. The lower dispersion limit for perception affections is roughly estimated as 0.67.

The material is thus divided into conduction affections and perception affections by this line which runs parallel with the axis of ordinates. Parallel with the axis of abscissas are drawn two lines enclosing the doubtful zone mentioned under the Abs. measurings. By this zone the material — after the Abs. — is likewise divided into conduction and perception affections. As is clearly seen in the two diagrams the same ears disperse themselves in the same groups according to the two quite different classification methods.

The coordination system is divided into 4 quadrants by the 0.67-line parallel with the ordinate and the "doubtful zone" lying rectangularly on it. According to this combined classification the material clearly falls into 2 groups. In the left lower quadrant we find the conduction affections, in the right upper quadrant the perception affections. At the boundaries lie the previously mentioned ears. They are given numbers just as the single ears, which deviate from the main groups. It is seen that the ears of a few patients which according to the proportion bone conduction/air conduction are characterized as doubtful, at these two frequencies lie in the same group (Nos. 46 and 67), but this has naturally no connection with the originally settled classification after the frequencies 512 and 1024 Hz.

CONCLUDING REMARKS

The results here obtained show with certainty a difference between the mean values for the Imp. measured on ears with conduction affections and on ears with perception affections

(and normal ears). This difference is so great that the areas which include twice the standard deviation and comprise 95 % of the cases at 512 and 768 Hz. overlap each other but very slightly.

The original aim — to examine if the Imp. measuring could be used in the diagnosis of conduction affections — may be looked upon as attained with a positive result. Some normal and pathologic ears which differ from the majority should however be taken into consideration.

Isolated ears with normal hearing have a very low Abs., and some ears with conduction or perception affections are placed in a dubious border zone or in "the wrong area".

Normal hearing combined with low Abs. can be explained in different ways.

1) There are possibly perfectly normal ears with a very low Abs. The most probable is however — as mentioned in chapter VI — that these ears are not normal, but

2) pathological without the sound conduction being affected. The low Abs. may be due to an increased stiffness of those parts of the drum, which are *not* in firm connection with the sound conduction chain, i. e. a change of the Imp. of the drum has occurred without any change of the energy supply to the labyrinth. From this there naturally is a gradual transition to a third possibility.

3) There is a reduction in the sound transmission — only that it does not cause any clinically demonstrable loss of hearing. For all organs it probably holds that the function can be decreased in a lower or higher degree without causing any subjective symptoms. When an objective demonstrable decrease in the function appears, will depend on the accuracy of the examination methods.

As previously mentioned, a determination of the hearing faculty with the aid of ordinary clinical audiometry is rather rough. Possibly an accurate determination of the sensibility of the ear — regard being paid to the increase in pressure due to reflection from the drum, which is of importance in these very cases — would be able to reveal a hearing loss in the normal ears with low Abs.

It is at any rate reasonable to imagine that the Imp. measuring, as the first accurate objective examination method of the sound conduction apparatus, will be able to reveal a decrease of the function of this in some ears which would previously have been regarded as normal.

No doubt, therefore, we will have to reckon with the first of the possibilities mentioned at the end of the introduction to the clinical part: Change of the Imp. of the ear drum without change of the energy supply to the labyrinth, even if it is not yet possible to decide whether there is a potential or a demonstrable change in the energy supply.

At the *hard-hearing ears* diagnostical difficulties will occur if such a "normal" ear with low Abs. is attacked by a perception affection. The low Abs. will have the effect that a conduction affection is presumed or, at any rate, a combined hardness of hearing.

Inversely a relatively high Abs. was in isolated cases also found in conduction affections associated with normal ear drums.

If it is regarded as less likely that there are perfectly normal ears with very low Abs., that will then mean that both the two mentioned possibilities: change of Imp. of the drum without change of the energy supply to the labyrinth, and change of the energy supply to the labyrinth without change of the Imp. of the drum, may occur. In the examined material consisting of 47 hard-hearing patients with normal drums there are however only very few ears which deviate in this way.

As an aid to the differential diagnosis between sound conduction and perception affections the Imp. measuring may further be used for examining the contraction of the intra-aural muscles. The acoustic measuring brigde is particularly suited for this.

The applicability and importance of Imp. measuring in the otological clinic may be regarded as being established.

The advantages of the acoustic measuring brigde have been emphasized in the present work. Especially in measuring small changes of the Imp. within the favourable measuring range

— as just on examination of muscle contractions — the bridge is a very exact instrument.

The disadvantages of the acoustic measuring bridge are obvious. The purely technical difficulty of getting an airtight connection with the ear has been mentioned. It is not suitable for measurements of very small Abs. and great changes of Abs., such measurements are just required in the examinations of the conduction affections. Possibly the measuring range by insertion of acoustic resistances may be removed so that it will always be in the most suitable place.

Another — also purely physical problem — is to find corrections for the olive with a smaller tube diameter than that used here, so that narrow meatus no longer cause any difficulty.

It is a difficult problem to extend the measurable range of the acoustic bridge to the deeper and higher frequencies. The importance of being able to determine the Imp. just at the deepest and highest audible frequencies and thus get an Imp. curve which includes this whole tone range is obvious. The range of frequencies which has been used at the present examinations only includes a very small part of the range employed in audiometry. Only in a very few cases has a difference been found in the change of Imp. at the deeper and higher frequencies, and in no case has it been possible to attach importance to it. One may in reality as well be satisfied with one frequency, f. i. 512 or 768 Hz., which have proved to be the best suited.

It will perhaps prove to be most practical to use an electro-acoustical method for the Imp. measurings also on ears. It is possible and, perhaps, also probable that the great progresses of electro-acoustics during the war also may be applicable in this field and that the methods can be simplified so that they also can be used in the clinic.

Seen from the viewpoint of the otologist it would be a great advantage if it would be sufficient to connect a small apparatus (a telephone) with the ear and make the measurements on a possibly bigger apparatus placed on a table alongside the patient.

SUMMARY

INTRODUCTION

This work begins with some remarks about the development of the acoustic function diagnosis. As it has not as yet been possible to find a practically applicable method for direct demonstration of a reduction of the vibration faculty of the sound conduction apparatus, a subjective function diagnosis based on the results of the different hearing tests is at present used almost exclusively also for the diagnosis of the conduction affections.

A new attempt to demonstrate a conduction affection by means of a direct objective method is motivated by the development of the physical and physiological acoustics during recent years, which makes it possible to determine the vibration faculty of the sound conduction system from new points of view and with new measuring methods.

PHYSICAL PART

I. The writer gives a very brief account of some fundamental acoustic principles. The mechanical impedance (Imp.) is the complex proportion between force and velocity, whereas the acoustic Imp. is the complex proportion between sound pressure and rate of volume displacement, the rate of volume displacement being the rate of particle displacement multiplied by the surface.

The absorption coefficient (Abs.) (a) and the phase change (the Phase) (ϑ) are defined, and the relation between these magnitudes and the components of the Imp. are reviewed. A coordinate system is used, in which the Imp. is represented by a vector, and the magnitude of a and ϑ as well as the components of the Imp., w and q, can be read directly.

After some general remarks on the energy absorption of a sound receiver, a brief description is given of the ear as acoustic receiver.

II. Some electro-acoustic methods for measuring impedances that physicists have used for measuring on ears (for the first time by *West* in 1928) are mentioned.

By the introduction of purely acoustic methods the determination is simplified considerably. The measuring bridge constructed in 1934 by *Schuster*, which was used for the present examinations, is explained. Its calibration, which differs somewhat from that suggested by *Schuster*, is described in detail. The importance of sources of error in measuring constant impedances as well as the accuracy of the measurements and their reproducibility through longer periods are investigated.

CLINICAL PART

III. As an introduction to the clinical part some remarks are set forth about what information of the sound conduction apparatus may be expected from the determination of the Imp. in a certain plane in the meatus ("measuring plane").

Then the relatively few methods reported for examination of the mobility and vibration faculty on the living ear are mentioned. Particular attention is called to a paper published by *Lucae* in 1887.

The results of the Imp. measurings made by physicists are reviewed.

IV. The employed *technique* is described.

V. *Sources of error in ear measurings.* As sources of error are regarded all changes and differences in the measured Imp. which are not due to mechanical conditions in the vibrating part of the sound conduction apparatus itself.

The sources of error, the causes of which are situated *outside* the ear drum, develop partly by the connection of the apparatus to the ear, partly — dependent and independent of this — as a consequence of difference of the Imp. in that part of the meatus which is situated between the "measuring plane" and the drum. These sources of error have been examined separate-

ly with the aid of model and preparation experiments, partly on the living ear.

As several of these sources of error appear together and may act in the same direction or may counteract each other, it is difficult in this way to find an expression for the measuring errors encumbering ear measurements.

A source of error *in the ear drum itself* is membrana flaccida, which is a loose membrane that can perform vibrations independent of the remaining part of the drum. Changes in its Imp. may be able to change the Imp. in the measuring plane — without affecting the energy supply to the labyrinth.

A couple of possible sources of error *medially to the drum* are mentioned, but with the exception of a case with an open tuba they have not been examined more closely. The sources of error in or medially to the drum are discussed in the introduction to the clinical part.

VI. *Impedance measuring on normal ears.*

A. In order to ascertain the dispersion (or the measuring error) several serial measurements were made *on the same normal ears.* At 512 Hz. there was thereby found a mean dispersion of the Abs. of about 3%, of the Phase about 2°.

Measurings on different days also usually lie within this dispersion area, but both on repeated measurings on the same day and on different days variations of the Imp. may be found that cannot be explained through the measuring errors.

As possible causes of these variations in the Imp., differences of pressure in the middle ear and in the state of contraction of the intra-aural muscles are assumed.

The pressure in the middle ear. Even in case of very small changes of the middle ear pressure in positive or negative direction, experiments performed on fresh temporal bones as on the normal ear present distinct changes of the measured Imp. Negative or positive pressure usually gives rise to a change mainly of the reactance component of the impedance, subsequently the resistance component decreases, and the Imp. more and more approaches a condition of pure reactance.

The loss of hearing seems to be of the same range of magnitude as the Imp. change.

Results are mentioned of examinations of a patient with a tuba aperta and of another one with an occlusio tubae.

A mode of procedure is suggested for ear examinations especially with a view to the pressure in the middle ear. The examination series includes an examination of the pressure in the middle ear according to the method given by *Dishoeck*, whose apparatus (designated as Pneumophon) consists in a slight modification of the employment of the acoustic measuring bridge. Moreover determination of the tuba permeability according to *Zöllner*'s method but with the change of Imp. as an indicator if the air penetrates into the middle ear.

The contraction of the intra-aural muscles. The most important results with regard to the function of the intra-aural muscles are summarized. The contraction of the stapedius muscle has during the last years been examined by several examiners on ears with perforation, so that a direct examination of the stapedius tendon was possible.

For the examination of the muscle contraction on normal ears no applicable method has been available as yet.

A contraction of the intra-aural muscles elicited acoustically from the opposite ear gives rise to a very distinctly — with the aid of the acoustic measuring bridge — demonstrable change of the Imp. There is mainly a question of a decrease of the Abs., being in many cases a pure change of Abs., in some cases accompanied by a small change of the phase too. The change is rather small. With the irritant employed (Bárány's noise apparatus) it corresponds to a reduction of the absorbed amount of energy of about 5 db at the highest, often less.

On examining a person who was able voluntarily to contract the tensor tympani, a change of Imp. was found in the same direction but more pronounced than at an acoustically produced contraction.

Two patients with unilateral trigeminius paresis are described here.

Only a couple of patients with unilateral facial paralysis were examined. They presented no difference between right and left ear (possibly because there was no stapedius paralysis).

B. Measurings on *different ears.* As normal material were used 30 persons in whom neither the anamnesis nor the examination disclosed any signs of ear affection. Nine of these were perfectly healthy, 13 patients with slight pulmonary tuberculosis not confined to bed and the 8 patients admitted to the Ear Clinic of the Rigshospital for other reasons than ear affections.

The values found are compared with those of previous examiners.

As the dispersion is much greater than the dispersion found by serial measurements on the same ear (for 512 Hz. 12 % against 3 %), it must for the greater part be caused by differences between the examined ears. How much importance should be attached to the section of the meatus situated between the "measuring plane" and the drum can be estimated with the aid of the examinations discussed in Chapter V. The dispersion not only of the Phase but especially that of the Abs. exceeds what could be expected after the importance of the meatus + measuring error and should thus be due to differences in the drum + the sound conduction apparatus.

Especially the dispersion downward towards the low Abs. is of importance. Below an Abs. of 20 % measured with 512 Hz., are four patients, 3 of whom just were admitted to the ear ward for different reasons. Thus the Abs. of both ears of the same person is low.

The reflex muscle contraction could be elicited on 31 out of 37 ears. Most of the ears on which it could not be elicited were ears of those persons who were admitted to the ear ward.

VII. *The Impedance in sure conduction affections associated with changes of the drum.*

Firstly, 10 persons with unilateral pronounced changes of the ear drum due to inflammations or sequelae of such were examined. As to the Abs. the mean value of the 10 pathological ears was about 2—3 times lower than the mean value of the 10 opposite normal ears. The phase did not show any sure difference between the pathological and the normal ears.

Furthermore, some patients with bilateral conduction affections of this kind were examined. Totally 25 ears with con-

duction lesions due to inflammations or sequelae of such were examined. Only 3 ears had a relative great Abs. In two of these cases there was an explanation of the great Abs. (perforation, open tuba), in the third case the phase presented deviating conditions.

The mean Abs. value for the 22 remaining ears for 512 Hz. is about 9 %, for 768 Hz. about 14 % against the values of the normal material of 33 % and 51 %.

VIII. *Examination of a material of 47 patients with impaired hearing and normal ear drums.*

The patients (with the exception of the Ménière patients) were selected so that clear-cut cases were preferred, i. e. patients who according to the anamnesis could be assumed to suffer from either a perception or a conduction affection. Combined hardness of hearing is included, however, if it was first diagnosed during or after the examination.

According to the subjective function tests the material has been divided into conduction affections, perception affections and doubtful diagnoses, the main importance in cases of unilateral hard-hearing being attached to the result of Fowler's balance test, in cases of bilateral hard hearing to the proportion between bone conduction and air conduction.

IX. *The Impedance in Conduction Affections Associated with Normal Ear Drums.*

In most cases there probably is a question of otosclerosis. The Abs. is low. The mean values for 512 and 768 Hz. are respectively about 7 % and about 15 %. The Phase only at 768 Hz. shows a slight difference in the direction of a smaller Phase on the pathological ears. The mean values for the Phase is quite the same as in conduction affections *with* changes of the drum.

The magnitude of the Imp. change and, thus, the decrease of the amount of energy absorbed is estimated through a comparison with the values of the normal material.

For the two highest frequencies (768 and 1145 Hz.) to which importance alone can be attached at the estimation of the absolute values for the low Abs., the difference only corresponds to a reduction of the absorbed quantity of energy of 7 and 5

db. The hearing loss is 50—60 db, i. e. of quite a different range of magnitude. The difficulty of estimating the small Abs., with the procedure employed is emphasized.

In order to get an idea of how great a change of Imp. an isolated fixation of stapes will give, this has been examined on normal temporal bones. A change of Imp. is thus found which would give a reduction of the quantity of energy absorbed through the drum of no more than 1—2 db.

This difference between a stapes fixation on normal temporal bones and stapes fixation on the living ear with otosclerosis may possibly be explained in the first mentioned case presenting a greater possibility of loss of energy by movements between the auditory ossicles. Perhaps also a difference in the tension of the drum in the two cases may have contributed to it.

The reduction of the amount of energy absorbed through the drum in otosclerosis (and in most cases of conduction affections due to inflammations or sequelae of such) does not directly determine, nor can it be used as a measure for the magnitude of the hearing loss.

X. *The Impedance in Perception Affections.*

Ten patients with unilateral loss of hearing and nine patients with bilateral hard hearing of this type were examined. Neither with regard to the Abs. nor with regard to the Phase do the unilateral perception affections show any sure difference between the hard-hearing and the opposite normal ear. With regard to the bilateral perception affections both Abs. and phase are entirely withing the spreading area of the normal material.

XI. *Ménière's Syndrome.*

In this group four patients with unilateral and six patients with bilateral hearing loss were examined. The Imp. of none of these ears deviated from that of the normal.

On changing the pressure in the labyrinth on normal temporal bones a distinct — though slight — change of the Imp. measured in the meatus was found. Owing to the — relatively — considerable dispersion of the results in the measurements on ears, the negative finding in Ménière's syndrome can only be interpreted as suggesting that no decrease of the energy transport to the labyrinth has occurred.

XII. *Uncertain Diagnosis.*

This concerns 3 patients with unilateral and one patient with bilateral hearing loss. Imp. measuring in connection with an examination of the muscle reflexes make a diagnosis possible which cannot however be controlled by the subjective hearing tests.

XIII. *The Contraction of the Intra-aural Muscles* in hard-hearing ears with normal drums.

In none of the hard-hearing ears with conduction affections can a muscle reflex be elicited.

With the exception of one ear a muscle contraction can be elicited in all the ears with unilateral perception deafness or completely deaf ears from the opposite normal ears. The conditions are a little more complicated in the patients with bilateral perception deafness, as a muscle contraction can be elicited in many cases, in others not, without this definitely being dependent on the magnitude of the hearing loss. However, it is impossible to elicit a muscle contraction *from* any of the completely deaf ears.

Ménière's Syndrome. A muscle contraction can be elicited in both ears of the 4 unilaterally hard-hearing patients. Only 5 of the 6 bilaterally hard-hearing patients have been examined. The muscle contraction can be elicited in all the ears with the exception of one.

XIV. *Finally a comparison has been made of the grouping of the material of patients according to the subjective function tests and after the Imp. measuring.*

This has been done partly by comparison of mean values and standard deviation with introduction of all the measuring results in the complex plane. (Fig. 27 and 28). (The signatures denoting the diagnosis according to the subjective function tests), partly — with regard to the bilaterally hard-hearing persons — by plotting them in a coordinate system, where the proportion bone conduction/air conduction (abscissae) is compared with the absorption (ordinates) (Fig. 29 and 30).

RÉSUMÉ

INDLEDNING

Der indledes med nogle Bemærkninger om Udviklingen af den akustiske Funktionsdiagnostik. Da man ikke hidtil har kunnet finde nogen praktisk anvendelig Metode til direkte Paavisning af en Nedsættelse af det lydledende Apparats Svingningsevne, benyttes — ogsaa til Diagnose af Lydledningslidelser — for Tiden næsten udelukkende en subjektiv Funktionsdiagnostik baseret paa Udfaldet af de forskellige Høreprøver.

En Genoptagelse af Forsøgene paa ved en direkte, objektiv Metode at paavise en Lydledningslidelse motiveres ved den fysiske og fysiologiske Akustiks Udvikling de senere Aar, der gør det muligt ud fra nye Synspunkter og med nye Maalemetoder at bestemme Lydledningsapparatets Svingningsevne.

FYSISK DEL

I. Der gives en meget kortfattet Fremstilling af nogle Grundbegreber fra Akustikken. Den mekaniske Impedans (Imp.) er det komplekse Forhold mellem Kraft og Hastighed, den akustiske Imp. det komplekse Forhold mellem Lydtryk og Volumenhastighed, hvor Volumenhastigheden er Partikelhastigheden multipliceret med Fladen.

Absorptionskoefficienten (Abs.) (a) og Fasespringet (Fasen) (ϑ) defineres, og Sammenhænget mellem disse Størrelser og Imp.'s Komponenter gennemgaas. Der benyttes i det følgende et Koordinatsystem, hvor Imp. fremstilles ved en Vektor og Størrelsen af a og ϑ saavelsom Imp.'s Komponenter w og q direkte kan aflæses.

Efter nogle almindelige Bemærkninger om en Lydmodtagers Energioptagelse følger en kortfattet Fremstilling af Øret som akustisk Modtager.

II, Nogle elektro-akustiske Metoder til Maaling af Imp.er, der af Fysikere (1. Gang *West* 1928) er benyttet til Øremaalinger, omtales. Indførelse af rent akustiske Metoder gør Bestemmelsen betydelig enklere. Den til de efterfølgende Undersøgelser benyttede af *Schuster* 1934 konstruerede Maalebro gennemgaas. Dens Justering er foretaget paa en noget anden Maade end angivet af *Schuster*, og fremstilles derfor detailleret. Betydningen af Fejlkilder ved Maalinger af konstante Imp.er undersøges ligesom Maalenøjagtigheden og Maalingernes Reproducerbarhed over længere Tidsrum.

KLINISK DEL

III. Som Indledning til den kliniske Del fremsættes nogle Betragtninger over, hvilke Oplysninger om Lydledningsapparatet man kan *vente* at faa ved at bestemme Imp. i et bestemt Plan i Øregangen (»Maaleplanet«).

Dernæst omtales de fra den otologiske Litteratur kendte, relativt faa Metoder til Undersøgelse af Lydledningsapparatets Bevægelighed og Svingningsevne paa det levende Øre. Særlig et Arbejde af *Lucae* fra 1867 fremdrages.

Resultaterne af de af Fysikere gjorte Imp.maalinger paa Ører gennemgaas.

IV. Den benyttede *Teknik* beskrives.

V. *Fejlkilder ved Øremaalinger.* Til Fejlkilder regnes alle Ændringer og Forskelligheder i den maalte Imp., som ikke har sin Aarsag i mekaniske Forhold i selve den svingende Del af det lydledende Apparat.

De Fejlkilder, hvis Aarsager er beliggende *udenfor* Trh., opstaar dels ved Tilslutning af Apparatet til Øret, dels — afhængigt og uafhængigt heraf — som Følge af Forskel i Imp. i det Stykke af Øregangen, som ligger mellem »Maaleplanet« og Trh. Disse Fejlkilder er undersøgt enkeltvis, dels ved Hjælp af Model- og Præparatforsøg, dels paa det levende Øre. Da flere af disse Fejlkilder oftest optræder sammen og kan virke i samme Retning eller kan modvirke hinanden, er det vanskeligt paa denne Maade at finde et Udtryk for Maalefejlen ved Øremaalinger.

En Fejlkilde *i selve Trh.* er membrana flaccida, som er en

slap Membran, der kan udføre Svingninger uafhængigt af den øvrige Del af Trh. Ændringer i dens Imp. maa kunne ændre Imp. i Maaleplanet, — uden at Energitransporten til Labyrinten paavirkes.

Et Par enkelte mulige Fejlkilder *medialt for Trh.* nævnes, men de er med Undtagelse af et Tilfælde med en aabentstaaende tuba — ikke nærmere undersøgt. Fejlkilderne i og medialt for Trh. er iøvrigt omtalt i Indledningen til den kliniske Del.

VI. *Impedansmaaling paa normale Ører.*

A. For at finde Spredningen (eller Maalefejlen) er gjort flere Maalerækker paa *de samme normale Ører.* Der findes herved med 512 Hz. en Middelspredning af Abs. paa ca. 3%, af Fasen ca. 2°.

Ogsaa Maalinger forskellige Dage ligger sædvanlig indenfor dette Spredningsomraade, men saavel ved gentagne Maalinger samme Dag, som ved Maalinger forskellige Dage kan man faa Variationer i Imp., der ikke kan forklares ved Maalefejlene.

Som mulige Aarsager til disse Variationer i Imp. tænker man sig Forskelligheder i Mellemøretrykket og i de intraaurale Musklers Kontraktionstilstand.

Trykket i Mellemøret. Selv ved ganske smaa Ændringer af Mellemøretrykket i positiv eller negativ Retning findes saavel ved Forsøg paa friske Tindingeben som paa det normale Øre tydelige Ændringer af den maalte Imp. Ved tiltagende negativt eller positivt Tryk faar man sædvanlig først en Ændring overvejende af den elastiske Blindkomponent, senere aftager Tabsmodstanden, og Imp. nærmer sig mere og mere til at blive en ren Blindmodstand.

Høretabet synes at være af samme Størrelsesorden som Imp. Ændringen.

Der meddeles Resultater af Undersøgelse af en Pt. med en tuba aperta og en anden Pt. med en occlusio tubae.

Man foreslaar en Fremgangsmaade til Øreundersøgelse specielt med Henblik paa Trykforholdene i Mellemøret. I Undersøgelsesrækken medtages Undersøgelse af Mellemøretrykket efter *Dishoeck*'s Metode, hvis Apparatur (den af D. benævnte

Pneumophon), man har i selve Maalebroen. Endvidere Bestemmelse af Tuba's Permeabilitet efter *Zøllner*'s Metode, men med Imp.ændringen som Indikator for om Luften trænger op i Mellemøret.

De intra-aurale Musklers Kontraktion. De vigtigste Resultater vedrørende de intra-aurale Musklers Funktion resumeres. Kontraktionen af m. stapedius er de sidste Aar undersøgt af flere Undersøgere paa Ører med Perforation, saaledes at direkte Iagttagelse af Stapediussenen var mulig.

Til Undersøgelse af Muskelkontraktionen paa normale Ører har man ikke hidtil haft nogen anvendelig Metode.

En fra det modsidige Øre akustisk udløst Kontraktion af de intra-aurale Muskler giver en ved Hjælp af Maalebroen meget tydeligt paaviselig Ændring af Imp. Det drejer sig hovedsagelig om en Formindskelse af Abs. I mange Tilfælde en ren Abs.ændring, i nogle Tilfælde ledsaget af en lille Ændring ogsaa af Fasen. Ændringen er ret lille. Med det anvendte Irritament (Bárány's Larmapparat) svarer den til en Nedsættelse af den optagne Energimængde paa højst ca. 5 db, ofte mindre.

Ved Undersøgelse af en Person, der vilkaarligt kunde kontrahere m. tensor tympani, fandt man en Ændring af Imp. i samme Retning, men mere udtalt end ved den akustisk udløste Kontraktion.

Der beskrives paa dette Sted 2 Ptt. med eensidig Trigeminusparese.

Der er kun undersøgt et Par Ptt. med eensidig Facialisparalyse. De frembød ingen Forskel mellem højre og venstre Øre (muligvis fordi der ikke var Stapediusparalyse).

B. Maalinger paa *forskellige Ører.* Som Normalmateriale er benyttet 30 Personer, hvor Anamnese og Undersøgelse ikke frembød noget Tegn paa Ørelidelse. De 9 var fuldstændig raske Personer, 13 oppegaaende Ptt. med lettere Lungetuberkulose, og de 8 Ptt. indlagt paa Rigshospitalets Øreafdeling af anden Grund end Øresygdom.

De fundne Værdier sammenlignes med de tidligere Undersøgeres Resultater.

Da Spredningen er langt større end Spredningen ved Seriemaalinger paa samme Øre (for 512 Hz. 12 % mod 3 %), maa den for Størstedelen være foraarsaget af Forskelligheder mel-

lem de undersøgte Ører. Hvor stor Betydning, der maa tilskrives det mellem »Maaleplan« og Trh. liggende Stykke af Øregangen, kan vurderes ved Hjælp af de i KapitelV omtalte Undersøgelser. Spredningen af saavel Fasen som særlig Abs. overstiger, hvad man kan vente efter Betydningen af Øregangen + Maalefejl, og maa altsaa ogsaa skyldes Forskelligheder i Trh. + det lydledende Apparat.

Særlig Spredningen nedadtil mod de lave Abs. har Betydning. Under en Abs. paa 20 % maalt med 512 Hz. ligger 4 Personer, hvoraf netop de 3 var Ptt. indlagt paa Øreafdeling af forskellige Aarsager. Det er altsaa begge Ører paa samme Personer, som ligger lavt.

Den reflektoriske Muskelkontraktion kunde udløses paa 31 af 37 Ører. De fleste af de Ører, hvor den ikke kunde udløses, var netop paa de omtalte Personer indlagt paa Øreafdeling.

VII. *Impedansen ved sikre Ledningslidelser med Trh.forandringer.*

Der er først undersøgt 10 Ptt. med eensidige, udtalte Trh.-forandringer paa Grund af Betændelser eller Følger heraf. For Abs.'s Vedkommende var Middelværdien af de 10 patologiske Ører ca. 2—3 Gange mindre end Middelværdien af de 10 modsidige normale Ører. Fasen viste ikke nogen sikker Forskel mellem de patologiske og de normale Ører.

Yderligere er undersøgt nogle Ptt. med dobbeltsidige Ledningslidelser af denne Art. Ialt er undersøgt 25 Ører med Ledningslidelser paa Grund af Betændelser eller Følger heraf. Kun 3 Ører har en relativ stor Abs. I de 2 Tilfælde er der en Forklaring paa den store Abs. (Perforation, aabentstaaende tuba), i det 3. Tilfælde viste Fasen afvigende Forhold.

Middelværdien af Abs. er for de øvrige 22 Ører med 512 Hz. ca. 9 %, med 768 Hz. 14 % mod Normalmaterialets Værdier 33 % og 51 %.

VIII. Derefter er undersøgt et *Patientmateriale paa* 47 *Ptt. med Hørenedsættelse og normale Trh.*

Ptt. er (med Undtagelse af Ménière-Ptt.) udvalgt saaledes, at man har foretrukket rene Tilfælde, d.v.s. Ptt., man efter Anamnesen kunde formode, havde enten en Perceptions- eller en Ledningslidelse. Kombinerede Tunghørigheder er dog med-

taget, hvis de først er diagnosticeret under eller efter Undersøgelsen.

Materialet er efter de subjektive Funktionsprøver delt i Ledningslidelser, Perceptionslidelser og tvivlsomme Diagnoser, idet man ved de ensidigt tunghøre har lagt Hovedvægten paa Udfaldet af Fowlers Balanceprøve, ved de dobbeltsidigt tunghøre paa Forholdet mellem Benledning og Luftledning.

IX. *Impedansen ved Ledningslidelser med normale Trh.*

Det drejer sig sikkert i de fleste Tilfælde om Otosclerose. Abs. er lav. Middelværdierne for 512 og 768 Hz. er henholdsvis ca. 7 % og ca. 15 %. Fasen viser kun ved 768 Hz. en lille Forskel i Retning af en mindre Fase paa de patologiske Ører. Middelværdierne for Fasen er ganske de samme som ved Ledningslidelser *med* Trh.forandringer.

Størrelsen af Imp.ændringen og dermed Nedsættelsen af den optagne Energimængde vurderes ved Sammenligning med Normalmaterialets Værdier.

For de to højeste Frekvenser (768 og 1145 Hz.), som alene kan tillægges nogen Betydning ved Vurdering af de absolutte Værdier ved de lave Abs., svarer Forskellen kun til en Formindskelse af den optagne Energimængde paa 7 og 5 db. Høretabet er 50—60 db d.v.s. af en ganske anden Størrelsesorden. Vanskeligheden ved Vurdering af de smaa Abs. med den her benyttede Fremgangsmaade fremhæves.

For at faa en Formodning om, hvor stor en Imp.ændring en isoleret Stapesfixation vil give, er dette undersøgt paa normale Tindingeben. Man finder herved en Imp.ændring, som skulde give en Nedsættelse af den gennem Trh. optagne Energimængde paa kun ca. 1—2 db.

Denne Forskel mellem en Stapesfixation paa normale Tindingeben og paa Stapesfixationen paa det levende Øre med Otosclerose kan muligvis forklares ved, at der i førstnævnte Tilfælde er en større Mulighed for Energitab ved Bevægelser mellem Øreknoglerne. Maaske kan ogsaa en Forskel i Spændingsforholdene i Trh. i de to Tilfælde være medvirkende.

Formindskelsen af den gennem Trh. optagne Energimængde ved Otosclerose (og i de fleste Tilfælde ved Ledningslidelser paa Grund af Betændelser eller Følger heraf) bestemmer alt-

saa ikke direkte og kan ikke benyttes som Maal for Høretabets Størrelse.

X. *Impedansen ved Perceptionslidelser.*

Der er undersøgt 10 Ptt. med eensidigt Høretab og 9 Ptt. med dobbeltsidig Tghh. af denne Type. De eensidige Perceptionslidelser viser, hverken hvad Abs. eller Fase angaar, nogen sikker Forskel mellem det tgh. og modsidige normale Øre. For de dobbeltsidige ligger saavel Abs. som Fase fuldstændig indenfor Normalmaterialets Spredningsomraade.

XI. *Ménière's Syndrom.*

I denne Gruppe er undersøgt 4 Ptt. med eensidig og 6 Ptt. med dobbeltsidig Tghh. Ingen af disse Ører viser fra det normale afvigende Imp.

Ved en Ændring af Trykket i Labyrinten paa normale Tindingeben finder man en tydelig — men ringe — Ændring af den i Øregangen maalte Imp. Paa Grund af den — i Forhold hertil — betydelige Spredning af Resultaterne ved Maaling paa Ører kan man kun udlægge det negative Fund ved Ménière-ptt. som tydende paa, at der ikke er sket en Formindskelse af Energitransporten til Labyrinten.

XII. *Usikre Diagnoser.*

Det drejer sig om 3 Ptt. med eensidig og 1 Pt. med dobbeltsidig Tghh. Imp.maaling i Forbindelse med Undersøgelse af Muskelreflekserne muliggør en Diagnose, som altsaa ganske vist ikke kan kontrolleres ved de subjektive Høreprøver.

XIII. *De intra-aurale Musklers Kontraktion* paa tgh. Ører med normale Trh.

Paa ingen af de tgh. Ører med Ledningslidelser kunde der udløses nogen Muskelreflex.

Med Undtagelse af 1 Øre kan der udløses en Muskelkontraktion paa alle de eensidigt perceptionstgh. eller døve Ører fra det modsidige normale Øre.

For de dobbeltsidigt perceptionstgh.'s Vedkommende er Forholdene lidt mere komplicerede, idet der i mange Tilfælde kan udløses en Muskelkontraktion, i andre ikke, uden at der er nogen helt sikker Afhængighed af Høretabets Størrelse. Der kan dog ikke udløses nogen Muskelkontraktion fra nogen af de helt døve Ører.

Ménières Syndrom. Der kan udløses Muskelkontraktion paa begge Ører paa de 4 eensidigt tgh. Ptt. Kun 5 af de 6 dobbeltsidigt tgh. Ptt. er undersøgt. Muskelkontraktion kan fremkaldes paa alle Ører med Undtagelse af eet.

XIV. Til Slut er gjort en *Sammenligning af Inddelingen af Materialet efter de subjektive Funktionsprøver og efter Imp.-maalingen.*

Det er gjort, dels ved Sammenligning af Middelværdier og Standardafvigelse med Indførelse af samtlige Maaleresultater i det komplekse Plan (Fig. 27 og 28) (Signaturerne angiver Diagnoserne efter de subjektive Funktionsprøver), dels — for de dobbeltsidigt tgh.'s Vedkommende — ved Indførelse i et Koordinatsystem, hvor man sammenligner Forholdet: Benledning/Luftledning (Abscissen) med Absorptionen (Ordinaten) (Fig. 29 og 30).

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